REPORT ON THE

POST-2002 MISSION PLANNING WORKSHOP

Easton, Maryland

24-26 August 1998

NASA Earth Science Enterprise

Report prepared by

Dr. Charles Kennel
Dr. Edward Frieman
Dr. Berrien Moore
Dr. Lisa Shaffer

Table of Contents

Section 1:
INTRODUCTION AND BACKGROUND

Perspective

Over the next century, an international observing system that supports the science and policy of the global environment will be designed and operated. The need has emerged from the implications of scientific work that started some time ago. The possibility of global changes in the physical, chemical, and biological environment had been recognized in the nineteenth century and became a widely accepted idea in the twentieth. By the mid-1970s, there had emerged specific concerns which affect every nation, every decision entity, and every person on the globe; among them, stratospheric ozone depletion, climate change and greenhouse warming, and threats to the world's ecosystems and biodiversity.

The first institutional response came in the next decade. The World Meteorological Organization and other international bodies convened major world climate conferences in 1979 and 1989. From these and other meetings there emerged the conclusion that the implications of climate change should be assessed for development policy. In 1988, the Intergovernmental Panel on Climate Change, composed of hundreds of scientists from more than 50 countries, assumed responsibility for international assessments of climate change and its consequences. The Montreal Protocol on the limitation of ozone-destroying substances in the stratosphere was also signed in 1988. By this time, it was recognized that addressing the issues of global change entails an extraordinary integration of scientific work across numerous disciplines. The US Global Change Research Program (USGCRP) was created in 1990 to promote the necessary interdisciplinary integration in US agency programs. The World Climate Research Program and the International Geosphere-Biosphere Program were designed to play an integrating role at the international level.

The need to acquire multidisciplinary data and information on a global scale was recognized in these scientific and policy deliberations. Beginning in the mid-1980's, international scientific and operational groups began to propose conceptual designs of systems that address one or more of the components of the global environment. These plans, misleadingly called systems, include the Global Terrestrial Observing System (GTOS), the Global Climate Observing System (GCOS), and the Global Ocean Observing System (GOOS). The critical, if not dominant role, is played by remote sensing from space in all these plans. NASA's Earth Observing System was designed and funded as the cornerstone of the observational strategy of the USGCRP and related international efforts within the framework of an International Earth Observing System (IEOS) involving the efforts of several international partners. While IEOS did not develop as originally foreseen, it stimulated a broader look at observations from space and related in situ measurement strategies.

The Committee on Earth Observation Satellites (CEOS) was created in 1984 to coordinate space remote sensing programs at the international level, and now has eighteen space agencies as members. In 1992 for the United Nations Conference on Environment and Development, CEOS disseminated a detailed summary of the schedules and specifications of all the existing and planned Earth observing instruments to be flown in space. This was updated in 1995 and 1997, and complemented by a preliminary set of prioritized observing requirements from the three Global Observing System groups and other relevant global Earth science programs. CEOS agencies recognized that no science problem has been solved by space measurements alone, and nearly all space measurements require complementary measurements taken in situ. With this awareness, CEOS, led by Japan and the US, then called for an Integrated Global Observing Strategy (IGOS), to link space and in situ observations in a common strategic framework.

The broad outlines of what must be achieved by an Integrated Global Observing Strategy are clear. Scientific understanding is evolving; observational technology is evolving; new applications are being created; new policy issues are certain to emerge. Thus, the strategy must be designed to accommodate change. The strategy must address numerous scientific and practical objectives simultaneously. The strategy needs to encourage a seamless relationship between research and monitoring. The strategy must preserve the continuity of essential long-term measurements while responding to changing scientific and practical needs in the short term. The strategy must deal with space and in situ observations together. In the case of climate, the observing strategy will be designed and evaluated in the light of global numerical models, and must be responsive to policy issues raised by such groups as the Intergovernmental Panel on Climate Change. The strategy must promote broad international participation: to share costs; to secure adequate geographical coverage; and, most important, to build confidence among global decision-makers in the conclusions drawn from the use of the observations. The strategy cannot avoid dealing with the essential institutional issue of time scales. We must create decision processes that can endure for the times needed to document slow changes in the global environment, during which time political, practical, and scientific priorities will necessarily change.

Above, in brief outline, is the context in which the evolution of the Earth Observing System since its beginning in the planning efforts of the 1980's should be viewed. The present evaluation of its most recent evolutionary step can only be understood in light of past developments in science, policy, and observing strategy.

How the Earth Observing System Has Evolved

The Earth Observing System (EOS) has been a cornerstone of the US Global Change Program since its inception in 1990. The initial proposal for EOS, never implemented, was for two very large, multi-instrument, multidisciplinary platforms, EOS-A and EOS-B, to be launched by the space shuttle into morning and afternoon sun synchronous polar orbits. Identical copies of each platform were to be launched at five-year intervals so as to secure a 15-year comprehensive and continuous data set on the Earth system. It was thought fundamental to observe each spot on the Earth with a full array of Earth system science instruments simultaneously. The high cost of shuttle launches, the size and complexity of many of the proposed instruments, and the difficulty of integrating numerous instruments with conflicting requirements on the same platform were some of the reasons that the basic architecture of EOS was modified in 1992. At that time, it became clear that some of the proposed measurements could not be made economically with the technology available at the time; directed technology development to reduce the size and complexity of these instruments would be needed. Furthermore, not all the instruments needed to be used at the same time; ocean and land measurements would be made at different times. Thus, the remaining measurements could be separated with little loss of science content into three less complex missions plus a number of smaller ones. The three were EOS-AM1, which focuses on land measurements made from a morning orbit, EOS-PM1, devoted to climate and meteorology related measurements from an afternoon orbit, and EOS-CHEM, for tropospheric and stratospheric chemistry measurements. The basic comprehensiveness of the original EOS-A and B data sets was maintained by the addition of several smaller missions. These basic steps, and the delay in the launch dates for EOS PM1 and CHEM1, reduced the 15-year cost of EOS from $17B to about $8.5B.

The basic architecture established in the 1992 NASA review was implemented; EOS-AM1 will be orbited by an Atlas launch vehicle within the year, and EOS-PM1 and EOS CHEM1 are scheduled for launch in 2000 and 2002, respectively. Since for these missions there was more time to adopt the new smaller instrument approach, EOS-PM1 and EOS-CHEM1 could be launched using the smaller Delta rocket. A year later, WHEN THE PREVIOUS NASA-DOD partnership for Landsat collapsed, the Landsat-7 mission was added to EOS, without a compensating increase in funding. These spacecraft, plus certain ancillary flights, define the so-called "first round" of EOS.

NASA's implementation philosophy continued to evolve as its understanding of the EOS mission advanced. NASA recognized that the main cost-driver of the system was instrument size, which drove spacecraft and launch vehicle requirements. It began to be clear that reflight of the identical instruments on identical repeats of the same missions would not capture the cost savings and/or performance enhancements foreseeable with directed technology development. This was one of the primary issues reviewed at the "La Jolla Workshop" on EOS implementation conducted in 1995 by the Committee on Global Change Research as a prelude to its "Pathways" report.

The generally prevailing ideas on how to secure continuous data sets had proven to be too restrictive in the EOS context; NASA declared that the implementation of the second and third rounds should allow technological evolution in both instruments and spacecraft. NASA would of course need to invest in those activities, such as ground validation and instrument intercalibration, which relate the data sets taken by differing instruments with the same measurement objective. Although how the measurements were made would change, the basic types of measurements to be made would not, and NASA committed to collecting 24 basic data sets over (now) 18 years. In recognition of the need to continuously evolve EOS technology, NASA, led by the Goddard Space Flight Center, which was named as the lead center for the EOS program, committed to reviewing EOS implementation every two years, approximately the interval between major EOS launches. Putting these changes into place again reduced the cost of EOS, and thereafter congressional funding for EOS stabilized somewhat.

The complete 1998 Pathways report examined the development of all of global change science. It concluded that the EOS missions could and should be more clearly focussed on the key scientific issues that had emerged over the past ten years; furthermore, new scientific issues clearly require some new types of measurements. Thus, NASA concluded that both the scientific objectives and the technical implementation of EOS should evolve.

Time is short, but it is still possible to change the design and implementation of the second round of EOS. The challenge is to decide, in advance of the flight of AM1, but in light of knowledge gained, which data sets should be continued into the second round, and which should be de-emphasized to make room for new scientific objectives, so that EOS may be executed within its slowly declining cost envelope. The process NASA has set in motion to decide what to do, and the conclusions reached thus far, are the subjects of this report. The "Request for Information" (RFI) process that NASA has set in motion (described in the following section), the disciplinary reviews (section 5) and the present Interdisciplinary Panel Review conducted at a workshop in Easton, Maryland, on August 24-26 are the subjects of this document. NASA has made some adjustments to its plans on the basis of the discussions at the meeting of the Interdisciplinary Panel. The decision process will continue with a review by a special panel of the National Academy of Sciences/National Research Council.

The question of the long-range future of the measurement series initiated by EOS surfaced at the Easton workshop. This issue will necessarily dominate the next scientific review of EOS in five years, when the third round of EOS will be defined. How shall the measurements of importance to science and public policy be continued beyond the third round? At the present time, the most critical part of the debate focuses on the transition of certain EOS instrumental capabilities to the National Polar-Orbiting Environmental Satellite System (NPOESS) in 2009, but the overall issue is much broader than that. There is no policy framework for discussing the post-EOS era of remote sensing observations for Earth System Science. We will offer some preliminary thoughts on this important issue at the end of our report.

Section 2:
THE NASA PROCESS

The Earth Observing System (EOS) satellite missions AM1, PM1 and CHEM1, were conceived for broad-scope data gathering (as required for exploratory investigation in a wide field of Earth science) and, simultaneously, to provide a baseline for long-term global environmental monitoring from space. While the scientific objective of NASA - understanding the Earth environment as a fully interactive system - has not varied, budget limitations, changes in technology, and advancements in scientific understanding call for a review of the strategy to pursue this goal in the next decade, beyond the first series of EOS missions. In issuing a "Request for Information" to the Earth science community in 1998, NASA's Earth Science Enterprise (ESE) sought first to re-validate the linkage between its overall scientific goal - expanding knowledge of the Earth system - and the existing EOS measurement strategy, and, second, to identify emerging new research priorities. The "Request for Information" process is a new administrative procedure to involve, as directly and quickly as practicable, a wide range of investigators and partners in the conception of strategic plans for future NASA flight programs. This process is not intended as a one-time opportunity, but rather as the first of a series of consultations: the ESE intends periodically to refresh this planning process through similar consultations with the Earth system science and applications communities at appropriate intervals in the future.

The primary focus of the "Request for Information" (RFI) was to construct a nominal mission scenario, based on responses received to the "Request" and reflecting the scientific priorities formulated by national institutions (National Academy of Sciences/National Research Council) and international scientific bodies, such as the World Climate Research Program and the International Geosphere-Biosphere Program. NASA informed RFI respondents of its intent to promote a program of smaller satellite missions, with a shorter implementation cycle from inception to launch in order to allow faster response to new research priorities and to reduce the risk to overall program objectives from any single mission failure. *Smaller missions imply more focused mission objectives*, targeting specific scientific questions beyond the anticipated achievements of the first series of EOS and Earth Probe missions, as recommended explicitly in the "Research Pathways" report of the Committee on Global Change Research of the National Academy of Sciences. Advances in modeling of the interactive Earth system provide confidence that this strategy of simpler global observing projects, focused on narrower and more coherent science objectives, can still support the goal of the U.S. Global Change Research Program to embrace the full interdisciplinary range of Earth science research issues and understand the behavior of the Earth environment as a system.

The Request For Information Procedure

The purpose of the RFI process was to seek new ideas for space-based investigations and measurement concepts, to further develop the observation program initiated with the first series of EOS missions, and to take advantage of progress in instrument, spacecraft and information technology for further scientific advances and new applications within a lower cost profile. The RFI stated that the primary criterion for assessing the priority of new missions would be the significance of their scientific objective, and the maturity of technologies that would enable them.

One hundred responses were received. Step 1 of the RFI process involved scientific reviews by six panels covering complementary domains of Earth system science and applications:

- Atmospheric Chemistry
- Atmospheric Climate Physics
- Global Water Cycle, Hydrology and Mesoscale Weather
- Ocean and Ice
- Land cover, land use and terrestrial ecosystems
- Geodynamics and Geology

A survey of emerging science priorities by each of these disciplinary panels led to highlighting 23 mission concepts that were recommended for further technical and cost assessment. The mission concepts are described in the RFI Step 1 Briefing Book **[http://www.hq.nasa.gov/office/ese/nra/RFIdodge/Panelrev.html]**, together with a summary of science priorities identified by the Step 1 review panels. Twenty-two mission concepts were actually analyzed by NASA technical staff and an industrial contractor. (One mission concept - Earth magnetic field monitoring - could be pursued through NASA participation in satellite missions of opportunity led by international partners.) Implementation costs were estimated on the basis of a standard "cost model" based on the experience of similar past or current satellite missions; instrument development costs were estimated on the basis of data provided by RFI respondents and prospects offered by technology advances. Taking into account mission cost estimates and programmatic prospects for the Earth Science Enterprise, the mission concepts were consolidated into a nominal "mission scenario" for the period 2002-2010.

The nominal mission scenario and underlying programmatic guidelines were presented to a Post-2002 Mission Planning Workshop, held in Easton, MD (24-26 August 1998). The objective of the Workshop was to allow interactive discussions of the mission scenario by a representative group of RFI respondents and an Interdisciplinary Review Panel of independent scientific experts. This report completes the RFI process. The outcome of this strategic planning process will be provided to the National Academy of Sciences for its review. ESE will be guided by the recommendations of both the Interdisciplinary Panel from the Easton Workshop (this report) and the Academy in planning future flight missions.

Three Categories of Missions

In order to define more clearly the implementation procedures and constraints, in conformity with new guidelines adopted by the Enterprise, three distinct categories of missions were defined:

- **EOS follow-on missions** for systematic measurement of critical parameters.
- **Earth Probe missions** for exploratory research or focused process-studies.
- **Pre-operational Instrument Developments** to provide new or more capable sensors for operational observing systems.

The three components of the program are briefly described below and in the NASA report (known as the “Blue Book”) which is provided in its entirety as Appendix 1.

1. Systematic Measurement Missions

The first objective of NASA Earth Science Enterprise is to fulfill its commitment to the science community to maintain continuity of EOS measurements of critical Earth system parameters, and deliver consistent time series of global measurements over the period of time effectively required. The nominal plan of ESE is to meet this commitment within a sustained level of funding about 30% lower than comparable elements in the first EOS series.

In order to achieve this goal, NASA intends (1) to identify essential parameters requiring systematic measurement *from an Earth system science perspective* and (2) promote to the extent possible the convergence of its global observation program with the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program. Appropriate bridging missions are identified in the nominal scenario to ensure measurement continuity in the interim period until operational observing systems deliver the required information. Further, NASA intends to promote, to the extent possible, cooperation with private sector and international partners to implement joint projects that can provide research-quality global observations. The nominal plan mandates an evolution toward dedicated missions, each carrying a much simpler payload designed to provide a coherent set of measurements for a single primary science theme. The ESE will capitalize on infusion of advanced technologies to optimize instrument and platform design, and minimize new mission costs.

2. Discovery and Process-research Missions

Based on the assumption made above and estimated experimental mission costs, the nominal scenario would allow the implementation of a multi-disciplinary Earth Probe program (incorporating the Earth System Science Pathfinder program) including one discovery and process-research mission launch every nine months, beginning in 2004. The Enterprise did not commit to a set program of experimental satellite missions for the next ten years. The intent is to issue successive solicitations for proposals to implement comprehensive missions that address specified science themes. NASA will determine step by step the sequence of scientific disciplines addressed by the Earth Probe program, upon confirmation of scientific priorities by scientific institutions and bodies, consideration of technical and funding capabilities, and determination of opportunities for international cooperation.

3. Pre-Operational Instrument Developments

Implicit in the planning strategy outlined above for systematic global observations is the assumption that NASA will invest sufficient effort to enable operational Earth observation programs, such as NPOESS and GOES, to provide long time-series of consistent, research-quality measurements. The procedure to achieve the desired convergence and establish effective arrangements for joint participation in the development of these prototype operational sensors is being worked at the present time. NASA indicated readiness to invest in the development and/or flight demonstration of advanced observing capabilities that meet operational needs as well as long-term Earth science objectives, when such projects are supported by a commitment of responsible operational agencies to participate in the development of the new sensors, and to implement their transition to operational use. The ESE would insert such pre-operational instrument developments into its flight mission program by re-ordering mission priorities in the systematic measurement, discovery or technology demonstration components (New Millennium Program) of the nominal mission scenario.

Section 3:

THE EASTON WORKSHOP

The Easton Workshop consisted of discipline-focused panels and an interdisciplinary review panel. Experts were invited in the fields of atmospheric chemistry, atmospheric climate and water cycle, oceanography (including ecosystems) and polar, land cover and terrestrial ecosystems, geology and natural hazards/applications. They were joined by observers from other U.S. Government agencies (FEMA, NOAA, FEMA, NSF, USGCRP, OMB, NPOESS IPO) and non-U.S. organizations (DLR, CNES, CSA, ESA, NASDA, EUMETSAT, and the Brazilian Space Agency). A list of invitees is included as Appendix 2.

The agenda is provided in Appendix 3. The purpose of the workshop was to review candidate missions and mission scenarios for the period 2002-2010. The workshop was called upon to formulate recommendations to NASA regarding the balance between research disciplines in Earth system science, systematic measurements and exploratory research, science-driven programs and technology development or demonstrations.

The workshop began with overviews of the program, implementation process, and RFI process and nominal mission scenario. Chairpersons of the six Step 1 Review Panels summarized the emerging Earth system science questions identified in their respective disciplines, and the conclusions they reached concerning measurement and mission priorities in the next decade. Disciplinary groups then reviewed the nominal mission scenario in the light of science or application priorities in their respective disciplines and formulated views or recommendations regarding the balance of the nominal mission scenario. Breakout groups were formed for atmospheric chemistry, atmospheric climate and global water cycle, ocean and ice, land cover and terrestrial ecosystem research and applications, and geology, natural hazards and applications for consideration of the proposed new strategy and nominal mission scenario. The new chairpersons of these groups led the discussions, made notes, and viewgraphs, and presented their results in plenary. Their reports are given in Appendix 4. The Interdisciplinary Panel was asked to take a "broad, across-the-board" look at the plans and to endorse or recommend modifications to the strategy. Due to the magnitude of the task and the short time available in Easton, the interdisciplinary experts met, but chose to prepare their report via written inputs provided after the workshop. These summaries, provided in Appendix 5, address areas of agreement and describe issues and areas for further attention, as well as defining priorities in some cases. It is these contributions which form the basis for the recommendations and conclusions of this report.

Section 4:
THE NOMINAL MISSION SCENARIO

As a result of the process described above, NASA produced the "ESE Mission Scenario for the 2002-2010 Period." This scenario defines and proposes three types of mission concepts: EOS follow-on missions for data continuity, Earth Probe exploratory missions for discovery and process-oriented research, and operational instrument development projects to demonstrate candidates for long-term operational systems. Figure 1 summarizes this nominal mission scenario, which is explained in the Blue Book at Appendix 1.

The previous baseline dated April 15, 1997, before the Biennial Review that NASA undertook in the summer of 1997, shows the following missions in chronological order, with their follow-ons where such existed:

Mission	**Launch Date**	**Follow-on**	**Launch Date**
TRMM	6/97	TBD/ATMOS-A	
		CERES mid-incl FOO	2000
ACRIM	1998	TSISat	2001
AM-1	6/98	AM-2, incl LATI NMP EO-1 (99)	6/04
Landsat-7	9/98		
SAGE-3 on Meteor	6/98	SAGE-3 on Station	2001
		SAGE-3 mid-incl. FOO	2005
ADEOS-2/Seawinds	2/99	TBD (Metop?)	
Jason-1/Radar alt	1999	Radar-alt-2	2004
PM-1	12/00	PM-2	12/06
		NOAA-N	2007
Laser Alt-1	7/02	Laser Alt-2	7/07
SOLSTICE	12/02	SOLSTICE FOO	2008
CHEM-1	12/02	CHEM-2 Monitor (includes SAGE-3)	6/08
		CHEM-2 Process	12/08

Figure 1: Pre-RFI Mission Scenario

The Blue Book scenario does not alter the missions shown in the first column. However, it addresses an evolution in the approach to defining the follow-ons which was already foreseen with the Chemistry mission, where CHEM2 was divided into a monitoring mission and a process mission with different objectives, different payloads, and different launch dates. Displaying the follow-on column from the table above against the Blue Book nominal scenario shows the evolution. The table below does not address new exploratory/discovery missions in areas not previously addressed in the EOS scenario, i.e., gravity, soil moisture, ocean salinity, vegetation recovery, and cold land processes, nor the proposed approach for development of operational instruments.

Figure 2
Comparison of Mission Scenarios for Data Continuity

Mission	**Launch Date**	**Previous follow-on mission concept**	**Launch Date**	**Blue Book concept & dates**	
TRMM	6/97	TBD/ATMOS-A		Int'l Precip. Mission (03)	EOS-9 Global Pre-cip. Mission (09)
		CERES mid-incl FOO	2000		
ACRIM	1998	TSIsat	2001	EOS-4 TSIM (01)	TSI (04)
AM-1	6/98	AM-2 incl. LATI NMP EO-1 (99)	6/04	EOS-3 Land & Ocean Imaging (04)	
Landsat-7	9/98			EOS-1 Land Cover Inventory (04)	
SAGE-3 on Meteor	6/98	SAGE-3 on Station	2001	EX-2 Aerosol Radiative Forcing Research Mission	
		SAGE-3 mid-incl. FOO	2005		
ADEOS-2/Seawinds	2/99	TBD (Metop?)		EOS-5 METOP 1-3 (03), NPOESS (09)	
Jason-1/Radar alt	1999	Radar-alt-2	2004	EOS-6 NPOESS Alt (09)	
PM-1	12/00	PM-2A	12/06	AIRS & AMSU – EOS-2 Climate Variability (06)	
		NOAA-N	2007	NPOESS (09)	
Laser Alt-1	7/02	Laser Alt-2	7/07	EOS-10 Icesat-1 (01)	Icesat-2 (10)
SOLSTICE	12/02	SOLSTICE FOO	2008		
CHEM-1	12/02	CHEM-2 Monitor (includes SAGE-3)	6/08	EOS-7 Strat-CHEM/ISS (04)	Strat-CHEM (08)
		CHEM-2 Process	12/08	EX-1 Tropospheric Chemistry (at least 1 & ideally 2 missions)	
ERS-1,2				Envisat ASAR (00)	
Radarsat-1		Radarsat-2	2000	EOS-8 Experimental SAR (02)	

Section 5:
SUMMARY OF DISCIPLINE PANEL INPUTS

This section summarizes the reports from discipline-focused experts in Easton, reviewing the Step 1 results and nominal Blue Book scenario. These reports were the inputs to the Interdisciplinary Panel whose recommendations follow in Section 6.

Atmospheric Chemistry

The disciplinary group reiterated the conclusions of the Step 1 Panel, which were incorporated for the main part in the nominal flight mission plan. They agreed in particular with a strategy based on systematic measurements of a limited range of key constituents in the stratosphere, and broad, discovery-type, experimental missions for investigating tropospheric chemistry. The gist of their recommendation addressed issues not related to flight missions, such as inter-disciplinary linkages (with Atmospheric Physics, in particular) and the need for a comprehensive research plan combining optimally in situ measurements with satellite observation, global data analysis with modeling, professional investigator research with student involvement. They also expressed concern about the capability of the NPOESS program to fully embrace research-quality measurement objectives.

Atmospheric Physics, Global Water Cycle and Hydrology

This group supported in essence the conclusions of the two independent Step 1 Panels that addressed Atmospheric Radiation Research and Basic Atmospheric Variables on the one hand, and Hydrology/Mesoscale Weather Research on the other. The group based its recommendations on the Blue Book and highlighted only three substantial issues:

- The group questioned ESE's assumption that Japan would lead a global precipitation mission as a follow-on to TRMM in the first half of the next decade and recommended the Global Precipitation Measurement Mission be advanced in time to the 2003 time-frame.
- The group recognized that similar low-frequency microwave radiometry techniques could be applied to estimate soil moisture (or wetness) and sea surface salinity, but recommended that NASA not delay an experimental mission aimed soil moisture until the more demanding needed to measure ocean salinity could be achieved.
- The group indicated its support for an Experimental Geostationary Research Mission suitable, in particular, for mesoscale meteorological studies but failed to identify specific research objectives in this domain.

Ocean and Ice

The disciplinary group considered the nominal mission scenario in the light of the priorities laid out by the Step 1 Panel, and focused its attention on specific discrepancies.

- The group supported the first priority given by the Step 1 Panel to the continuity of systematic global ocean topography measurements and questioned the feasibility of achieving scientifically adequate precision with altimetric measurements from low-altitude polar platforms. Further, the group noted that the first NPOESS mission that may accommodate a radar altimeter (5:30 am equator crossing time) will not fly in the next decade, owing to the number of DMSP spacecraft yet to be used on this orbit. Under these circumstances, the group expressed concern that a large data gap will occur in this fundamental oceanic record between the end of the Jason-1 mission and the first possible NPOESS replacement.

- The group highlighted the significance of ocean-surface (vector) wind measurements and recommended that NASA continue the Seawinds program on a follow-on mission after ADEOS-2

- The group regarded the continuity of systematic ocean color measurements the third highest priority for ocean sciences, agreed that the Advanced Global Imager sensor proposed in the nominal scenario could provide adequate baseline measurements, but and questioned the possibility of obtaining research-quality data from NPOESS in early morning and afternoon orbits.
- The group highlighted the significance of global salinity data to understand the world ocean circulation and supported the concept of an experimental ocean salinity-measuring mission.

- The group endorsed the incorporation of systematic precision altimetry measurements in the nominal scenario but recommended that such observation be maintained continuously.

- The group recommended programmatic coordination with NOAA/NESDIS to allow the development of new sensors, such as the Special Event Imager, on operational geostationary satellites.

Land Cover and Terrestrial Ecology Research

The land group generally supported the provisions made in the nominal scenario to maintain the continuity of two essential data records for global land cover inventory (Landsat follow-on) and global ecosystem productivity (medium-resolution multi-spectral imaging) missions. The group further supported the priority given to experimental observation of ecosystem response to natural and anthropogenic disturbances. However, the group recommended that a more ambitious range of co-registered active (lidar), hyperspatial (1 meter-class imaging), multi-angular and hyperspectral observation be considered for the experimental "ecosystem response" mission.

In general, the group emphasized the importance of nurturing interdisciplinary ecosystem science through a comprehensive program capable of integrating data from a variety of sources, including commercial observing systems. These concerns will be taken into account of the NASA science plan.

Solid Earth, Natural Hazards and Applications

The disciplinary group was generally able to endorse the nominal mission scenario, as part of a broader comprehensive research strategy integrating in situ observation, with some specific recommendations:

- The group considered that the scientific return of a (transient) gravity field-mapping mission justifies continuation as a systematic measurement.

- The group emphasized the importance of an Experimental Geostationary Research Mission, in particular for the research on rapidly evolving processes and the development of sensors for natural hazard warning applications.

In general, the group felt that all missions considered in the nominal scenario should be optimized to serve application objectives.

Section 6:
SUMMARY OF INTERDISCIPLINARY PANEL INPUTS

Analysis of the comments and recommendations of the interdisciplinary panel at the Easton workshop shows that, with a few exceptions, there is general agreement with the NASA “Blue Book” nominal mission scenario. Participants expressed overarching concerns about the long-term continuity of critical observations; the adequacy of NPOESS to meet scientific requirements in certain areas; the need for increased attention to data integration across missions and between space-based and in situ observations; facilitation of interdisciplinary research; and the need for increased attention to applications uses of the data and information from the NASA ESE program. These concerns are summarized in Section 8.

Significant issues concerning the nominal mission scenario are summarized below.

Atmospheric Climate Physics

This group had strong agreement with the nominal scenario.

- The panel supported the systematic measurement missions (EOS-2 Climate Variability and Trend; EOS-4 Total Solar Irradiance Monitoring), exploratory missions (EX-2 Aerosol Radiative Forcing Feedback; EX-3 Cloud Radiation Feedback), and preoperational instrument (OP-2 Tropospheric Wind Sounder) described in the Blue Book.

- They noted the importance of a geostationary program, and called for further study in this area.

- One recommendation is the addition of a wind measurement capability on EOS-2 with inclusion of a tropospheric wind profiler or planning a flight of an incoherent detection Doppler lidar system at the same time.

- They call for careful and extensive coordination with national and international partners and across different missions to maximize the return for the community.

Applications

- The Panel endorsed the continuity of systematic measurements at high and moderate resolution (EOS-1 and EOS-3) as well as continued ocean productivity with the Advanced Global Imager.

- The Global Precipitation Mission (EOS-9) was strongly endorsed with an equally strong recommendation that it be accelerated and worked with international partners.

- The Applications group endorsed OP-6, the Special Events Imager.

Oceans and Ice

- The Oceans and Ice interdisciplinary panel affirmed the essential elements of the report from the Ocean and Ice Technical Panel.

- The highest priority for the scientific missions during the 2002-2010 period is maintaining continuity and information content in the several critical oceanographic measurements through EOS-6 Ocean Surface Topography, EOS-5 Ocean Surface Winds, EOS-3’s ocean color capability, and EOS-10 Polar Altimetry.

- The group expressed concern about the detailed implementation of these capabilities in terms of timing, data continuity, calibration, orbital characteristics, and international partnerships.

- They endorsed the ocean salinity component of EX-4, follow-on gravity measurements with EX-5, and the Special Events Imager (OP-6).

Hydrology and Global Water Cycle

- The principal systematic measurement recommendation from this group was the Global Precipitation Mission EOS-9 with the same call as the Applications panel to proceed without waiting for the Japanese ATMOS-A.

- Exploration of soil moisture through EX-4 was endorsed, with a request that the mission not be delayed for technology development in ocean salinity observations.

- A snow and ice exploratory mission was endorsed which appears consistent with the concept of EX-7 Cold Land Processes.

- This group also recommended an additional exploratory mission for measuring river and lake stages.

Atmospheric Chemistry

The report from the Atmospheric Chemistry team was more complex in its response to the NASA nominal scenario, but basically endorsed the discipline breakout group's report.

- In addition to the Stratospheric Composition (EOS-7), they advocated a mission to continue total column ozone and one for ozone profiles (using multiple components in different orbits).

- Within the concept of the EX-1 Tropospheric Chemistry Research Mission, the interdisciplinary team recommended a Global Pollution Mission and a mission to look at the upper troposphere and lower stratosphere.

Solid Earth Science and Natural Hazards

- The Solid Earth Science and Natural Hazards group strongly supported a SAR interferometry mission which could be EOS-8 Topography and Surface Change, giving more detailed specifications for performance than the NASA mission concept.

- The Time-Dependent Gravity Field Mapping Mission EX-5 was endorsed, as well as OP-5 the Volcanic Ash and Gas Emission Mapping Mission from geostationary orbit.

- An additional mission to map the time-varying global magnetic field was proposed as well.

Section 7: COMPARISON OF MISSION SCENARIOS*

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
Land Use/Land Cover (10-20 m)	Global Land Cover Inventory Mission (LCTE) (Landsat continuity)—should consider including 1-3 m panchromatic band	High Resolution Mission (Harriss)	Many economically important applications in addition to key science. (Harriss) Consider flying Land Use and Global Ecosystem missions together on same platform. (LC/TE)
Climate Variability & Trend – temp, moisture profiles – bridge between PM1 & NPOESS	Variability & Trends in Basic Climate Variables (Smith)	Climate variability and Trend (Tropospheric sounding measurements of temperature and humidity) (Hallgren)	The science questions are reasonably well articulated and address needs that have been expressed by national and international groups. Temperature and moisture observations for detection and attribution of global warming must be more accurate than those planned for the NOAA satellites in the next decade (Hallgren) Atmos. Temp, moisture, and TOA radiation fluxes to fill gap.

Blue Book	Discipline Panel Recommendations	Interdisciplinary Panel Recommendations	Comments
Global Terrestrial and Oceanic Productivity Mission (coarser resolution, bridge between MODIS & NPOESS) could include AGI	Global Ecosystem Productivity (LC/TE) (MODIS continuity)	Moderate Resolution Mission (Harriss)	LC/TE priority concern on AM gap, more important than PM1-> NPOESS. Prefer VIIRS fill-in to allow understanding of instr. and minimal cost. Want to rely on operational systems. Need to know more about foreign plans in 2005+ time frame
	Ocean Color w/AGI (O&I) Advanced Ocean Color Mission (O&I) (not nec. Hyperspectral, but w/high radiometric sensitivity)	Advanced Global Imager (Harriss)	AGI - important bridging mission to continue moderate-resolution multispectral imaging of land and ocean ecosystems in “gap” between EOS Phase 1 and NPOESS. Will be the fundamental tool for assessing climate-biosphere interactions (Harriss)
		Ocean Color continuity (Tapley)	Morning orbit gap-filler betw. MODIS & VIIRSS. Data quality, orbit etc. important; need one tilting sensor or 2 non-tilting (O&I)
Total Solar Irradiance Monitoring Program	Variability in Solar Forcing (Smith)	Total Solar Irradiance (Hallgren)	The science questions are reasonably well articulated and address needs that have been expressed by national and international groups. (Hallgren) Required continuation between TSIM and NPOESS (Smith)

Blue Book	Discipline Panel Recommendations	Interdisciplinary Panel Recommendations	Comments
Ocean Surface Wind	Vector Wind Measurements (O&I)	Vector Wind Measurements (Tapley)	2nd priority for O&I. METOP scatt inadequate. Need bridge betw. ADEOS-2 & NPOES (O&I)
Ocean Surface Topography	Ocean Altimetry (O&I)	Ocean Surface Topography (Tapley)	Continuation of T/P class sea surface topography is highest priority. Cannot justify ANY gap in coverage; orbit is important (O&I)
Stratospheric Composition		Total Column Ozone (Wofsy)	Nadir mapping instrument in polar orbit, following on the various TOMS mission and the ozone column mapper on the EOS-CHEM platform. Long-term calibration needed to define trends of 1%/decade makes this unsuitable for treatment as an operational instrument in the conventional sense. (Wofsy)
		Ozone Profile (Wofsy)	Occultation instrument like SAGE3. Need orbit or set of orbits that provide reasonable scanning of the occultations over a global range of latitudes, at a reasonable frequency. (Wofsy)

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
Stratospheric Composition (cont.)		Stratospheric Composition for limited suite of species (Wofsy)	2 Platforms: mid-inclination FTIR and visible occultation instrument attached to the ISS & polar orbiter with microwave/IR emission instruments and occultation instruments. (Wofsy)
Topography and Surface Change	InSAR Surface Deformation – 2-satellite L-band mission (SES/NH)	SAR Interferometry (Solomon)	mm-level line-of-sight distance accuracy; 30-100 m positional accuracy, targetability and repeatability of viewing scenes over full range of latitudes. Belongs high on NASA's priority list for systematic measurement. (Solomon)
	High resolution topography, follow-on to ICESAT		Investigate various technologies and commercial partnerships (SE/NH)
Global Precipitation (after ATMOS-A)	Global Precipitation (Smith)	Global Precipitation (Harriss, Bras)	Urgent and high priority from an applications perspective. Planning for this mission should be accelerated. (Harriss) Don't wait for ATMOS-A (Bras) Move up to 2003 (Smith) Synergy with Cloud Radiative Forcing mission – implement in same timeframe w/shared instrument program (Smith)

Blue Book	Discipline Panel Recommendations	Interdisciplinary Panel Recommendations	Comments
Polar Altimetry – ice sheet mass detection and balance	Polar Altimetry (O&I)	Polar Ice Mass Change Time Series (Tapley)	Study whether 5-year gap is acceptable (O&I)
Tropospheric Chemistry research Mission		Global Pollution Mission (Wofsy)	Possible instruments include spaceborne DIAL and UV and IR nadir sounders/mappers. We envision a strong technology development program in this area to enable a future mission. (Wofsy)
		Upper Troposphere-Lower Stratosphere Mission (Wofsy)	Temperature, ozone and water vapor in the upper troposphere, tropopause region, and lower stratosphere, e.g., upper tropospheric water vapor using microwave limb sounding. Technology development effort needed to mature new methods for quantifying these parameters near the tropopause followed by a lean, low cost space mission. (Wofsy)

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
Aerosol Radiative Forcing Research Mission	Aerosol Radiative Forcing Feedback (Smith)	Aerosol Radiative Forcing research (Hallgren)	Cloud-Radiation Feedback and Aerosol Radiative Forcing Missions require observations of a number of common parameters. Independence of these missions be preserved and the synergism between them be maximized through extensive and intensive early planning (Hallgren) Highest priority for Atm. Climate (Smith). Synergy with global precip. Mission (Smith)
Cloud-Radiation Feedback Research Mission	Cloud-Radiative Forcing Feedback (Smith)	Cloud radiation feedback (Hallgren)	Cloud-Radiation Feedback and Aerosol Radiative Forcing Missions require observations of a number of common parameters. Independence of these missions be preserved and the synergism between them be maximized through extensive and intensive early planning (Hallgren) Dedicated mission w/Active & passive sensors (Smith)

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
Soil Moisture & Ocean Salinity Observing Mission	Comprehensive ocean/air interface mission focusing on salinity & soil moisture (O&I) Soil Moisture (Smith)	Soil Moisture (Bras)	Technological challenge but high payoff for salinity measurements w/accuracy of 0.1 to 0.3 PSU can be achieved. (O&I) Don’t hold back soil moisture to wait for salinity technology (Smith)
		Ocean Salinity (Tapley)	
Time-dependent Gravity Field Mapping	Temporal Variation of Gravity Field (SE/NH) GRACE follow-on (O&I)	Time-dependent Gravity Field mapping (Tapley, Solomon)	GRACE follow-on mission be placed in the ‘systematic’ category, due to the value of continuous long-term measurements of temporal gravity field changes (SE/NH) Shd be experimental mission until GRACE results can be evaluated (O&I)
Vegetation Recovery Mission	Ecosystem Response to Disturbance Mission (LC/TE)		possibly involving a combination of remote sensing technologies: lidar, SAR imaging, hyperspatial imaging, simple vegetation index, wide FOV sensor, multi-angle viewing, hyperspectral imaging (LC/TE)
Cold Land Processes Research Mission (snow & ground water) eg L-band SAR	Cold Processes Research (Smith) – snow cover, depth, snow-water equivalence	Snow & ice (Bras)	

Blue Book	Discipline Panel Recommendations	Interdisciplinary Panel Recommendations	Comments
INSTRUMENTS			
Advanced Microwave Sounder			
Tropospheric Wind Sounder	Tropospheric wind sounder shd be included in Climate Variability mission (Smith)	Tropospheric Wind profiler (Hallgren)	
GPS for Atmospheric Sounding			
Advanced Geostationary Sounder			
Volcanic Ash and Gas Emission Mapping Mission & advanced geostationary Earth Imager	Research geostationary platform for various applications (SE/NH)	Solomon: monitor natural hazards	
Special Event Imager (geo)	SEI for met & hydro observations, also canopy conductance and fire for diurnal sampling (LC/TE) Pointable imager for tidal effects on coastal ecosystems (O&I)	Special Event Imager (Harriss, Tapley)	could potentially provide unique, high frequency observation of episodic processes in terrestrial and coastal ecosystems that are not easily captured by a dedicated mapping mission (Harriss)
Lightning Mapper (geo)			
	Surface Water Measurement – lake and river heights to estimate discharge (Smith)	Measuring River & Lake Stages (Bras)	
	Continued Magnetic Field Measurements (SE/NH)	Time-varying global magnetic field (Solomon)	Continuation beyond 2005 important. Pursue in partnership with foreign scientists, Code S. (SE/NH)
	Orbiting Transfer Radiometer (LC/TE)		

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
	Coarse resolution SAR (LC/TE)		
	Multi-angle observation (LC/TE)		
	Mesoscale weather (Smith)		Requires advanced geostationary spacecraft – operational adjunct mission (Smith)

*References are to input given at Easton and immediately thereafter:

Interdisciplinary Panels:
Bras: Hydrology and Global Water Cycle
Harriss: Applications
Hallgren: Atmospheric Climate Physics
Solomon: Solid Earth Science and Natural Hazards
Tapley: Oceans & Ice
Wofsy: Atmospheric Chemistry (same report for discipline and interdisciplinary)

Discipline Groups:
LC/TE: Land Cover/Terrestrial Ecology (Janetos)
Smith: Atmospheric Physics, Global Water Cycle and Hydrology
O&I: Oceans and Ice (Freilich)
SE/NH: Solid Earth and Natural Hazards

Section 8:
RECOMMENDATIONS AND CONCLUSIONS

NASA's Earth science enterprise has a strong scientific foundation and a clear justification for continued support. The Easton workshop validated the science and demonstrated that the program continues to address key questions in Earth system science. The review also reinforced the important contribution that continued scientific progress can make in vital areas of public importance.

The process NASA undertook to refine its Earth science mission planning in light of the evolution in scientific understanding was the right thing to do. Changes in technology and advancements in science provided an opportunity to update the program and make it more effective. The 1995 La Jolla review and this 1998 process and workshop are responsive to the National Academy of Science's Pathways report. NASA should be commended on its willingness and dedication in trying to meet the concerns raised by the Academy.

> NASA should be commended for undertaking this review and for developing a more flexible and resilient program paradigm.

The evolution of NASA's program has led to a new paradigm which includes missions selected because they contribute to sustaining long-term measurements to meet defined observing requirements, and experimental missions that address new science areas, either process studies or discovery missions. In addition, NASA proposes to invest in developing new instruments and technology for future missions. The ability to evolve the scientific goals, the technological implementation, and the human and organizational participation in EOS should make the system more resilient over the long term. It is a new, still experimental way to achieve continuity of overall research strategy in a dynamically evolving environment.

The program review highlighted good new subjects that are worthy of serious study for inclusion in EOS, such as aerosols, clouds, soil moisture, and ocean salinity. These were not technically feasible at a low cost when EOS was first conceived but now the technology is within reach and the scientific need is well documented. The NASA mission scenario includes consideration of such missions. At the same time, NASA has identified experimental measurements such as precipitation, which are now ready to be considered for long-term systematic observation. This has resulted in a proposed global precipitation mission in the "Blue Book" plan. The new scenario also provides for an integrated strategy for the study of tropospheric ozone distribution and chemistry, with a balanced combination of airborne campaigns and global observation from satellites. NASA has also reached out more aggressively to the applications community to broaden the user base and the potential benefits from the nation's investment in the Earth science enterprise. It is clear that the science of the ESE can have an enormous positive impact on many communities not currently engaged in the program, and the attention to applications should help strengthen the communication and the linkages between the science and new end users.

There are areas of serious concern, however, in the new approach. The new freedom and flexibility has added risks of various kinds. These include greater uncertainty in the out years about the continuation of certain measurement series; increased complexity in integrating the various elements of the program into a coherent whole, and increased interdependence in many domains. The hazards are real and the time is short. Once the program is defined, NASA can address some of these issues. Others will require action at a higher level.

The benefits of the new NASA approach come with significant risks. These include uncertainty about continuity of measurement series; increased complexity and interdependence; and more challenges in achieving programmatic integration.

The single most critical concern is the lack of a national policy to address long-term measurements to meet known national and international needs. Some needs are driven by science, such as continued climate studies and improved weather predictions; some will be addressed by already planned operational systems (primarily NPOESS). Some long-term observing requirements stem from commitments made in international treaties such as the Montreal Protocol and the Framework Convention on Climate Change. Others are in areas where ongoing government services can be enhanced by the application of Earth science and space technology such as natural hazards detection and response, management of wilderness areas and agricultural monitoring.

The nation needs to consider the long-term future of the measurements being made or that will be made by the ESE that will demand a commitment beyond the current plans for NASA missions. Attention currently focuses on NPOESS. Here the concerns are twofold. First, for the measurements explicitly accepted as within the NPOESS mandate, there is no assurance that the quality of measurements, including accuracy, calibration, ground validation, and orbital parameters will be able to meet the scientific requirements. Second, there are many other measurements of importance that NPOESS has no mandate to make.

A new national policy is required to ensure the long-term continuity of key datasets needed to meet research, operational, and policy requirements. Without this commitment, NASA may find it difficult to fund new discovery-type missions needed to advance scientific understanding and stimulate technological progress.

A policy framework is needed to support a meaningful discussion of the long-term future of environmental measurements from space. U.S. commitments to the global observing systems (GCOS, GOOS, and GTOS) should be considered in this dialog. The role of other US Government agencies needs to be examined. It is not obvious that NOAA should be the only place to look for long-term sustained observations from space. Governments of other countries have committed to long-term space programs in Earth observation and there is active discussion to develop an Integrated Global Observing Strategy. The existing coordination frameworks that have become increasingly effective in planning weather satellite systems and research missions should be strengthened to encompass the whole suite of needed long-term observations. In addition, there is consideration of private sector roles in ultimately providing observations on a commercial basis and allowing governments to act as consumers. All these issues must be examined and a well-articulated national policy framework developed. This process should start now. The complexities of the situation will require difficult tradeoffs in areas such as sharing of intellectual property rights (between government and private sector and between governments) and reexamination of agency mandates.

Furthermore, there is more to meeting long-term observing requirements than just putting satellites in orbit. To effectively provide useful information, attention and funding must be provided for in situ measurements, and for the needed increases in computational capacity and modeling to integrate data from multiple sources and provide meaningful analysis. It is clear that NASA cannot be the only source for such programs, and that NASA and NPOESS together will not have the breadth and depth to meet the nation's needs. Unless we make a national commitment to sustaining key measurements needed for science, policy, and other applications, NASA will not be able to turn its attention to the unique contribution it can make in advancing the science and technology in Earth observations through discovery-type missions looking at new areas. The success of the "Blue Book" scenario is dependent on reducing NASA's role in long-term sustained observations through their eventual transition to another budget to free up resources for new missions. The "bridging" missions are an important and necessary NASA contribution to ensure that we have time to develop the needed policy.

In defining the process or discovery missions, NASA should pay particular attention to the programmatic breadth of the mission concepts to ensure that research in new areas has a fair opportunity for consideration along with more well established concepts. The RFI process can be a good tool, but must be openly and fairly implemented to ensure a breadth of new research opportunities.

The second fundamental concern is the challenge of program integration. The new paradigm is more complex than earlier EOS program approaches. There is an enormous challenge in meeting the goal of understanding the integrated Earth system while assembling observations from a wide range of focussed space-based and in situ observing projects. The policy of PI-led missions, each conceived and implemented in a different institution and subject only to "light-touch" NASA management, adds to the diversity which can enrich the program but adds to the complexity. Depending for critical measurements on other organizations within the US Government and abroad also introduces risk. Furthermore, providing sufficient computational, data system, and communication resources to support interdisciplinary research may be difficult to define, defend, and achieve.

> <u>By defining a more complex program with a greater number of smaller components and more players, NASA has made it more difficult to achieve an integrated program. Interdisciplinary research may require additional effort to bring together all the needed elements.</u>

The EOSDIS, which was not the subject of review in Easton, was intended to be a fundamental tool in serving the broad Earth science and applications community, and stimulating exchange and interaction among different disciplines and interdisciplinary scientists. When the short-term issues associated with getting the first round data collected, analyzed, and distributed are more clearly resolved, NASA and the community must take stock of the realistic expectations for EOSDIS and consider the evolution of EOSDIS in light of the evolution of the flight system and scientific.

> <u>The data and information system is still a critical element in the Earth science program and needs further examination to ensure that the user communities are able to easily obtain and meaningfully use the data and information acquired in the program.</u>

The social structures such as the Investigator Working Group for EOS and other forums for science community involvement should be examined to see how they can be adapted to the new program environment. NASA needs groups of knowledgeable researchers and representatives of other user groups such as emergency response agencies and operational users who can debate issues, consider tradeoffs, and advise NASA when tough decisions are needed. This will only happen if NASA has the needed administrative and management staff to support such processes.

In conclusion, EOS has become a flexible evolvable system for making measurements pertinent to Earth system science. There are exciting opportunities and formidable challenges ahead. With the support of a strong Earth science community, and the attention of policymakers, we can expect many new discoveries and great progress in the years to come.

Appendix 1

The NASA Blue Book
ESE MISSION SCENARIO FOR THE 2002-2010 PERIOD

INTRODUCTION

The strategic goal of the Earth Science Enterprise is to expand scientific knowledge of the earth system using the unique vantage point of space. To achieve this goal, the Enterprise recognizes that scientific progress results from a multiplicity of converging approaches. While the pursuit of Earth System Science would be impossible without the global coverage provided by space-based instruments, integrating knowledge from in situ and space observations is equally essential. For this reason, NASA in cooperation with other science-funding agencies supports a balanced program of investigations based on satellite, airborne and surface measurements, as well as modeling and theoretical studies. This research strategy will be presented in a comprehensive, inter-disciplinary Research Implementation Plan under preparation by the ESE.

Notwithstanding this on-going effort, there was immediate need to plan future flight missions, in order to guide technology investments and identify prospective commercial and international partners. The purpose of the Request for Information (RFI) issued by the Enterprise was to explore planning options for future ESE flight missions during the period 2002-2010, following the completion of the first EOS series, and to construct a nominal mission scenario based on responses received to the RFI. The scenario reflects the scientific priorities formulated by national institutions (National Academy of Science/National Research Council) and international scientific bodies, and takes into account technical feasibility, estimated mission costs, and projected funding levels. The Earth Science Enterprise intends to periodically refresh this planning process through similar consultations of the Earth system science and applications communities at appropriate intervals in the future.

NASA informed RFI respondents of its intent to promote a program of smaller satellite missions, with a shorter implementation cycle, from inception to launch, in order to allow faster response to new research priorities and reduce the risk to overall program objectives from any single mission failure. *Smaller missions imply more focused mission objectives*, as recommended explicitly in the "Research Pathways" report of the Committee on Global Change Research of the National Academy of Science. This strategy, based on smaller satellite missions focused on narrower and more coherent science objectives, does not imply a retreat from the goal of the U.S. Global Change Research Program to embrace the full range of disciplines in Earth science and understand the behavior of the Earth as a system. It is envisioned that comprehensive Earth system models will provide the means to realize the necessary inter-disciplinary synthesis and integrate data from multiple sources, space-borne remote sensing and in situ measurements.

The Request For Information Process

The purpose of the RFI process was to seek new ideas for space-based investigations and measurement concepts, to further develop the observation program initiated with the first series of EOS missions and take advantage of progress in instrument, spacecraft and information technology to pursue scientific advances and new applications within a lower cost profile. The RFI stated that the primary criterion for assessing the priority of new missions would be the significance of their scientific objective beyond the anticipated results of the first EOS series, and the maturity of required technologies. One hundred responses were received.

Step 1 of the RFI process consisted in scientific reviews of these responses by six panels covering complementary domains of earth system science and applications:

- Atmospheric Chemistry
- Atmospheric Climate Physics
- Global Water Cycle, Hydrology and Mesoscale Weather
- Ocean and Ice
- Land Cover, Land Use and Terrestrial Ecosystems
- Geodynamics and Geology

A survey of emerging science priorities in each disciplinary panel led to highlighting 23 mission concepts that were recommended for further technical and cost assessments. The mission concepts are described in a white Briefing Book, together with a summary of science priorities identified by the Step 1 review panels. Twenty-two missions concepts were actually analyzed by NASA technical staff and an industrial contractor. (One mission concept - Earth magnetic field monitoring - could be implemented through NASA participation in satellite missions of opportunity led by international partners.)

Step 2 of the RFI process begun with estimating Implementation costs, using a standard "cost model" developed by industry and based on the experience of past satellite missions. Instrument development costs were for the main part evaluated on the basis of information provided by RFI respondents, taking into account expected technology advances. Finally, the mission concepts were consolidated into a nominal "mission scenario" for the period 2002-2010, taking into account mission cost estimates and programmatic prospects for the Earth Science Enterprise. The nominal mission scenario and underlying programmatic guidelines were presented to a Post-2002 Mission Planning Workshop, held in Easton, MD (24-26 August 1998). The purpose of the Workshop was to allow discussion of the nominal scenario by a representative group of RFI respondents and an Interdisciplinary Review Panel of independent scientific experts. Specifically, the Workshop was asked to respond to three overarching questions:

- Is the nominal mission scenario consistent with the **key scientific questions formulated by national and international bodies** representing the Earth System Science community?
- Is the **balance between scientific disciplines** reflected in the nominal mission scenario consistent with emerging frontiers in Earth System Science?
- Does the balance between **systematic measurement and discovery or process research missions** reflect an effective strategy to address key science questions in Earth System Science?

The report of the Workshop's Interdisciplinary Review Panel completed the RFI process. The ESE has requested that the National Academy of Science assess the resulting mission scenario, as amended as a result of the Step 2 Workshop.

Three Categories of Missions

Different implementation procedures and constraints may apply according to mission objectives.

For clarity, three categories of missions were distinguished:

- **EOS follow-on missions** for systematic measurement of key earth system parameters.
- **Earth Probe missions** for exploratory research or focused process-studies.
- **Pre-operational instrument development** to provide new or more capable sensors for operational observing systems.

The three components of the program are briefly described below. In addition, the Enterprise is planning a University Earth System Science program (UnESS) of mini-missions, principally to serve educational objectives, capture the interest of the next generation of earth scientists and engineers, and encourage their participation in space remote sensing projects.

1. Systematic Measurement Missions

The first objective of NASA Earth Science Enterprise is to fulfill its commitment to the science community to maintain continuity of key EOS measurements, and deliver consistent time series of global observations over the period of time required by the nature of the earth system. The nominal plan of ESE is to meet this commitment within a sustained level of funding about 30% lower than comparable elements in the first EOS series.

In order to achieve this goal, NASA (1) proceeded to identify essential parameters requiring systematic measurement *from an earth system science perspective* and (2) promoted convergence of its global observation program with the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program. Appropriate bridging missions are identified in the nominal scenario to ensure measurement continuity in the interim period until operational observing systems deliver the required information. In addition, NASA will implement, to the extent possible, cooperation with private sector and international partners to implement joint projects that can provide research-quality global observations. Finally, the nominal plan calls for evolution toward smaller missions, each carrying a much simpler payload designed to provide a coherent set of measurements focused on a well-defined set of science themes.

2. Discovery and Process-research Missions

Based on estimated experimental mission costs, the nominal scenario allowed a multi-disciplinary Earth Probe program (incorporating Earth System Science Pathfinder missions) consisting of one discovery or process-research mission every nine months, beginning in 2004. Each mission is expected to provide a coherent set of measurements focused on a primary science theme. The Enterprise did not commit to a set program of experimental satellite missions for the next ten years. The intent is to issue successive solicitations for comprehensive mission implementation proposals addressing specific science themes selected by the agency. NASA will determine step by step the sequence of scientific disciplines addressed by the Earth Probe program, taking into consideration scientific priorities confirmed by scientific institutions and bodies, technical and funding capabilities, and opportunities for international cooperation.

3. Pre-Operational Instrument Developments

Implicit in the planning strategy for systematic global observation outlined above is the assumption that NASA will invest sufficient effort in technology and advanced operational instrument development to enable operational Earth observation programs, such as NPOESS and GOES, to provide research-quality measurements. The procedure to achieve the desired convergence and establish effective arrangements for joint participation in the development of these prototype operational sensors is being worked at the present time. NASA indicated readiness to invest in the development and/or flight demonstration of advanced observing capabilities that meet operational needs as well as long-term earth science objectives, when such projects are supported by a commitment of responsible operational agencies to participate in the development of the new sensors and implement their transition to operational use. The ESE would insert such pre-operational instrument developments into its flight mission program by re-ordering mission priorities in the systematic measurement, discovery or technology demonstration components (New Millennium Program) of the nominal mission scenario, as appropriate.

APPENDIX 1

SYSTEMATIC MEASUREMENT (EOS FOLLOW-ON MISSIONS)

Earth system science is dealing with a very complex dynamical system, governed by non-linear relations that can spontaneously generate variations of many time and space scales, from turbulent eddies to long-term changes in global ocean circulation. In addition, the system is subjected to a number of external forcing factors or changing boundary conditions. For lack of a capability to model and predict such external parameters (that may be controlled by inadequately known processes like solar activity, or changed by human actions), the only possible scientific strategy is the systematic observation of forcing and response, with the ultimate objective of linking one to the other. This is the fundamental reason why systematic observation and "climatological" data records play such an important role in this field of natural sciences.

The following represents a nominal mission plan for systematic measurement of atmospheric, oceanic and land variables to which Step 1 reviewers gave highest scientific priority *from an earth system science perspective*. The sequence of missions is ordered according to expected launch dates.

EOS-1: Land Cover/ Land Use Inventory Program

The Land Cover and Terrestrial Ecosystem research program calls for systematic measurement of changes in global land surface cover and land use, and estimation of their impact on the global carbon cycle, to be provided by a series of land imaging missions following Landsat-7. The same information is also essential for a wide range of value-added applications, such as forest and range management or agriculture. Each mission would carry one main instrument: multi-spectral (visible/near IR) imaging radiometer providing global coverage with sufficient spatial resolution (~10-20m) to unambiguously identify the extent of different type of vegetation or other land cover, and sufficient frequency (revisit time of the order of 15 days) to determine seasonal & long-term changes in terrestrial biomass. The instrument concept could be based on the Advanced Land Imager design being tested on the New Millennium EO-1 demonstration mission, with the addition of appropriate coarse-resolution spectral channels for atmospheric corrections. Progress in detector array technology, especially performance at non-cryogenic temperature, and high data-rate on-board processing are the main technology drivers for further optimization.

Implementation of the **first mission** in the series would begin in FY'01 for launch in year 2005, six year after the launch of Landsat-7. NASA intends to carefully examine private sector initiatives in this domain as a means for acquiring the relevant scientific data sets through data purchase instead of building a dedicated mission.

EOS-2: Climate Variability and Trend Mission

Most of what we currently know (or can infer) about the general circulation of the atmosphere and the global energy and water cycles is inferred from observation of basic meteorological variables, atmospheric pressure, temperature, moisture and wind. This information is obtained from a multiplicity of sources, in situ measurements by balloon-borne radiosondes at some 800 stations around the world and global remote sensing by atmospheric sounders on meteorological satellites. Currently, temperature and moisture profile data obtained from operational sounders suffer from significant weaknesses that make them less than ideally useful for atmospheric circulation analysis and forecasting (a large fraction of operational satellite sounder data is actually rejected by the more advanced data assimilation models). A decisive breakthrough is expected with the Advanced Infra-Red Sounder (AIRS), which is the first satellite sensor that can emulate the temperature and moisture measurement accuracy of radiosondes. It is expected that AIRS data will be available for the expected six-year lifetime of the PM-1 mission.

NASA is working closely with the NPOESS Integrated Program Office to enable similar temperature and moisture profile accuracy with the next-generation operational atmospheric sounder system that will be deployed on future operational environmental satellites. The objective of the *Climate Variability and Trend Mission*, given high priority by atmospheric climate research, is to continue research-quality temperature and water vapor measurements during the interim period between the termination of PM-1 and the first NPOESS flight. A single **bridging mission** is needed to fill the gap between EOS PM-1 and the first NPOESS satellite. In order to ensure measurement continuity, the mission would need to be launched no later than 2006, i. e. about six years after the launch of PM-1. NASA has selected several R. an D. projects under its Instrument Incubator Program (IIP) to develop the advanced technologies that can be applied to this mission.

EOS-3: Global Terrestrial and Oceanic Productivity Mission

The second highest scientific priority for Land Cover and Terrestrial Ecosystem research is systematic global observation of biological productivity at 1-2 day intervals at the best achievable spatial resolution (250-1000 m). Likewise, the oceanographic community gives high scientific priority to systematic observation of changes in ocean color and inferred ocean primary productivity. Moderate resolution global image data are also essential for a broad range of applications supported by NOAA, from smoke cloud detection to fisheries.

NASA's nominal plan in this domain is to promote the convergence of research and operational observation programs and eventually rely on NPOESS and other global operational observing systems in the future. A single **bridging mission** is needed to continue acquiring moderate-resolution multispectral imaging radiometer data from a morning orbit during the interval between the AM-1 mission and the first NPOESS flight. The nominal plan to fill this data gap would take advantage of the "Advanced Global Imager" (AGI) instrument currently under study jointly by NASA and the NPOESS program. For measurement continuity, the bridging mission would need to be launched no later than 2005, i. e. about six years after the launch of AM-1.

The Workshop agreed that the nominal plan, based on the use of the AGI instrument, could provide adequate baseline measurements but questioned the feasibility of obtaining research-quality data (especially ocean color measurements) from the NPOESS early morning and afternoon orbits. NASA agreed to study the impact of AGI design trade-off and NPOESS orbits from the perspective of marine ecosystem research and consider alternative means to acquire research-quality ocean color data.

EOS-4: Total Solar Irradiance Monitoring Program

The source of the energy that drives all climate processes is radiation from the Sun, known as the "solar constant" or, since we know now that the Sun is a (mildly) variable star, Total Solar Irradiance. NASA and other space agencies have maintained an essentially continuous record of total solar irradiance variations since 1979. NASA has undertaken the development of the next-generation total solar irradiance monitor (TSIM), to be flown in 2001 on a scientific satellite mission of opportunity built by Canada (SciSat). The plan is to eventually rely on measurements planned by the NPOESS program, beginning at the end of the decade. NASA made sure that the specifications of TSIM meet NPOESS requirements for solar irradiance monitoring.

In order to maintain the integrity of the total solar irradiance record, it is essential that successive TSIM missions provide sufficient overlap, since the stability (relative accuracy) of individual spaceborne radiometers is at least one order of magnitude better that their absolute calibration, and systematic differences between one instrument and the next can be as large as or larger than the signal. It is expected that one **solar irradiance monitoring mission** will be needed to ensure measurement continuity in the second half of the next decade (launch in 2005). The mission could be implemented on a small free-flying platform or as an instrument on space flights of opportunity. In addition, NASA is planning an intercomparison program of flight instruments with a laboratory-calibrated reference radiometer embarked on the Space Shuttle.

EOS-5: Ocean Surface Wind Measurement Program

The acquisition of surface wind data, interrupted in 1997 as a result of the premature shut-down of the NASDA/ADEOS satellite, will be resumed in late 1998 with the launching of the "QuikSCAT" recovery mission (using the first flight model of the new-generation SeaWinds sensor developed by NASA), to be followed by the ADEOS-2 mission carrying the same SeaWinds instrument in the year 2000 time frame.

The nominal NASA strategy for surface wind data acquisition in the long term is to rely on global measurements provided by two operational observing systems:

- Passive dual-polarization microwave radiometer on the NPOESS satellite series during the next decade of the next century.
- ASCAT active microwave scatterometer on the European METOP satellite series under development by EUMETSAT, with first launch planned in 2003.

The Workshop highlighted the importance of ocean surface (vector) wind data and insisted on the importance of full global coverage (which cannot be provided by a single ASCAT system) in order to capture fast weather developments and intense storms which contribute a disproportionate amount to mean oceanic forcing. NASA agreed to study the impact of data gaps in the coverage by a single scatterometer system. In addition to Europe's operational meteorological satellite program, the private sector also expressed interest in developing a constellation of small satellites equipped with scatterometers to provide global vector wind data. NASA plans to examine both operational agencies (NPOESS and EUMETSAT) and private sector plans prior to deciding on the development of a dedicated mission beyond Seawinds-1 on the Japan's ADEOS-2 mission. NASA also received informal indication of Japan's interest in flying a SeaWinds-class instrument on the ADEOS-3 mission.

EOS-6: Ocean Surface Topography Mission

At the present stage of development, the highest priority for global oceanography is the continuity of essential dynamical measurements: ocean surface topography and ocean surface wind. NASA and the French space agency CNES cooperated to implement the very successful TOPEX/Poseidon ocean altimetry mission launched in 1992 and still operating nominally after six years. The US/French Jason-1 mission (to be launched in year 2000) will continue this key oceanographic measurement at the same or even better level of accuracy.

The nominal NASA strategy for global ocean topography observation is to rely on radar altimeter measurements from operational polar-orbiting satellites. Achieving the required (centimetric) accuracy from low-altitude sun-synchronous polar orbit, combining measurements from several platforms for appropriate temporal/spatial sampling, and correcting for solar tidal effects still poses scientific and technical problems. It is expected that these feasibility issues will be resolved by the Geosat and Jason-1 missions. Plans to proceed with the implementation of this measurement on NPOESS are being developed.

The Workshop concurred with the conclusion of the Step 1 reviewers that continuity of global ocean topography measurements has first priority for ocean circulation studies and climate research. The Workshop was concerned by the likelihood that a large data gap would occur between the Jason-1 ocean altimetry mission and the first NPOESS mission carrying a radar altimeter (early morning NPOESS spacecraft only), currently scheduled for 2011. Furthermore, the Workshop questioned the feasibility of achieving scientifically adequate precision and space-time sampling with altimetric measurements from low-altitude polar platforms. NASA agreed to investigate further the scientific and technical problems involved in ocean altimetry from polar spacecraft, and to consider the means to ensure the continuity of research-quality ocean topography measurements. In addition, NASA selected several R. an D. projects under the Instrument Incubator Program to develop the advanced technologies applicable to this mission.

EOS-7: Stratospheric Composition Measurement Program

The foremost scientific problem in the field of atmospheric chemistry remains the stabilization and eventual recovery of the stratospheric ozone layer. (Is the Montreal Protocol working as expected? Could other factors not yet recognized impair the recovery?). Considering that stratospheric chemistry is a relatively mature field, first priority for the discipline is given to monitoring the ozone distribution as a function of halogen concentration, trace gases and aerosols in the stratosphere.

A long-term systematic stratospheric composition measurement program would focus on accurate (essentially self-calibrating) observation of a relatively limited selection of precursor and reservoir species at the minimum sampling rate that allows reliable detection of trends. Measurement methods of choice are solar occultation radiometry or spectrometry, and atmospheric limb emission radiometry. In order to achieve adequate geographic coverage, the mission requires a 2-spacecraft constellation, one in sun-synchronous orbit and the other on an inclined (50-60¡) orbit.

Implementation of the sun-synchronous component could begin in FY'04 for launch of the first spacecraft of the series in late 2008, six year after EOS-CHEM. The nominal option for implementation of the inclined-orbit component is a succession of attached payloads on the International Space Station (ISS). Fabrication of instruments for the attached payloads could be completed in a 2-3 year period beginning in FY'02 or 03.

EOS-8. Topography and Surface Change Mission

Land surface topography is a fundamental geophysical parameter that influences the interaction between the atmosphere, hydrosphere and solid earth, and a key observable for assessing natural hazards such as floods, coastal storm surges, landslides, etc. Changes in topography provide information on crustal strain that is essential to understand the physics of solid earth and may provide precursor signal to impending natural hazards such as earthquakes and volcanic eruptions. Detailed topography of the polar ice sheets also yields critical information on ice flow dynamics and, indirectly, the changing mass balance of the ice sheets.

The solid earth and polar science community place high scientific value on repeat synthetic aperture radar (SAR) mapping of land surface and ice, and specifically the implementation of a tandem SAR mission that would allow the best possible interferometric reconstruction of global topography (comparable in principle to, but more precise than, the Shuttle Radar Topographic Mission in 1999). Emerging applications in the domain natural hazard reduction provide a strong incentive to maintain nearly continuous SAR coverage of the earth through the next decade. Significant periods of overlap between successive missions would allow implementing bistatic radar interferometry.

NASA intends to carefully examine private sector investments in the field of global SAR observation, beyond its first free-flying SAR mission planned in the early 2000 time frame, and plans to acquire the needed scientific data through data purchase whenever possible. Cooperation with international partners is also an open possibility to ensure observation continuity.

EOS-9: Global Precipitation Mission

The scientific focus of global water cycle research and hydrologic sciences is understanding and predicting the impact of climate change on weather events, river flow and water resources. The discipline recognized that global rainfall distribution is the foremost measurement required to progress toward quantitative knowledge of the water cycle and arguably the most accessible hydrologic quantity for satellite remote sensing. Among several possible techniques, passive and active (radar) microwave measurements from low earth orbit is the most mature and reliable approach.

Precipitation is associated with mesoscale weather systems that display considerable spatial and temporal variability. For this reason, high sampling frequency is essential: a sampling interval of three hours or less is required to estimate total rainfall reliably. Measuring rainfall from space would requires a constellation of at least 4 spacecraft in staged polar orbits. The nominal concept is to fly only one "master" rainfall-measuring satellite carrying both active (Precipitation Radar) and passive (Microwave Radiometer/Imager) sensors, and a number of "drone" satellites carrying only the passive microwave sensor. Considering that two DMSP spacecraft equipped with the SSM/I microwave radiometer are expected to be in operation, two drones would be sufficient to complete the constellation. The master satellite mission could be implemented on a dedicated platform, while the drones would be smaller free-flying spacecraft. The nominal plan was to begin implementation in FY'04, aiming for launch in year 2007 four years after the TRMM follow-on mission under consideration by NASDA.

The Workshop agreed that implementing the original objective of EOS to measure global precipitation had very high scientific value for the progress of earth system science. The Workshop further noted that the Japanese space agency's plan for a TRMM follow-on mission were not firm and recommended that the implementation of a global rainfall measuring mission be advanced to the 2003 time-frame. NASA agreed to carefully examine opportunities for an earlier implementation and explore possible international partnerships.

EOS-10: Polar Altimetry Mission

The central question of polar climate science is the detection of changes in ice sheet dynamics and mass balance. For this purpose, systematic precision measurements of Greenland and Antarctic ice sheet topography are needed at appropriate intervals. The first measurement will be provided by the ICESat mission (launch date: 2001) as part of the first EOS series. The nominal plan included a repeat mission around 2010, using either one of two possible techniques that may (precision lidar and synthetic-aperture radar altimeter).

The Workshop highlighted the importance of precision altimetry as the centerpiece of a systematic measurement strategy for ice-sheet dynamics and ice mass balance studies, and expressed concern about the expected discontinuity between the first ICESat mission and a repeat mission launched near the end of the next decade. NASA agreed to assess the scientific impact of a discrete (discontinuous) sampling strategy for the study of ice sheet dynamics.

APPENDIX 2

EXPLORATORY AND PROCESS RESEARCH-ORIENTED MISSIONS

Progress toward more a fundamental understanding of the earth system, based on first physical, chemical or biological principles, will primarily result from process-oriented research or discovery missions. Such missions will need to collect adequate but not necessarily complete global data sets that sample the full global range seasonal and geographic conditions for periods of (typically) 3 to 5 years. Such research missions can be taken as the discovery component of the ESE flight program. They respond to the recommendation of the National Academy of Science/National Research Council to promote an innovative program of focused research satellite projects addressing sharply defined science questions.

Exploratory missions may entail high scientific and technical risks, as investigators try to break into new fields of investigation, and attack unsolved scientific questions with the resources of the latest technology. It would be unwise at any time to define a ten-year program of experimental missions that would ignore future prospects for new scientific ideas, new technological advances and unforeseen science breakthroughs. In this regard, it is best to select each new experimental mission through a solicitation process open to a range of competing projects as late as possible in the implementation process, following a practice pioneered in the Earth System Science Pathfinder program.

On the other hand, it is essential to correctly gauge the scope of the exploratory mission program that would optimally balance the systematic measurement component in the overall research strategy for the Enterprise. For this purpose, NASA applied the same scientific evaluation, technical feasibility and cost assessment procedures to both systematic measurement and discovery mission concepts. The candidate mission concepts described below are those that emerged as particularly promising in the Step 1 review. This set should be considered as illustrative of the discovery missions that might be implemented in response to scientific priorities that will emerge in the next ten years, and does not suggest a particular implementation order. Several among these mission concepts have already been considered by partner agencies abroad and would therefore be good candidates for joint cooperative projects.

Each of candidate experimental mission listed below has been highlighted by Step 1 reviewers as essential for the advancement of their respective scientific disciplines and is representative of the state of the art. However, this set of mission concepts by no means represents the variety of meritorious ideas that were presented in the RFI process, nor the diversity of new proposals that may emerge in the future from regular Announcements of Opportunity or the next program-wide RFI. The ordering of the candidate missions *does not reflect a judgment of scientific priority*, and the actual Earth Probe mission program of the Enterprise remains to be determined by successive solicitations and a competitive selection process.

EX-1: Tropospheric Chemistry Research Mission(s)

Tropospheric chemistry is generally taken as the next frontier of global atmospheric chemistry. While ozone is a relatively minor constituent of the troposphere, ozone is specially important in tropospheric chemical processes as it reflects the oxidizing power (and cleansing effect) of the troposphere. Another essential research topic is the long-range transport and diffusion of pollutants from surface sources, and the global atmospheric impacts of large-scale pollution from emerging industrial nations.

Observation of chemical/dynamical processes in the troposphere faces two challenges: the need for sufficient vertical resolution to identify the layered structure of constituents transported by the atmospheric circulation and the need for adequate temporal resolution to resolve possible diurnal variations and fast emission events. The latter requirement would be ideally fulfilled by observation from geostationary orbit, except for the fact that feasible measurement are generally lacking in vertical resolution within the troposphere. Differential absorption lidar and other active sounding systems operating from low earth orbit can ideally meet the requirement for vertical resolution, but only provides relatively sparse sampling. The Step 1 review panel for Atmospheric Chemistry concluded that, given a choice between vertical resolution and high sampling frequency, the former had the highest potential for discovery. This scientific judgment is reflected by the scientific priority given to a number of promising measurement concepts in low earth orbit.

The scientific discovery potential of global tropospheric chemistry justifies **at least one and ideally two experimental missions** during the period of reference. Each would a one-time mission, carrying a payload limited to a small number of sensors (to be determined by the assessment of competing research mission proposals). The instrument payload could include passive and active sensors (such as tunable differential absorption lidars) to observe ozone, CO and precursor species, or pollutant emitted by surface sources (SO2, hydrocarbons, etc.).

EX-2: Aerosol Radiative Forcing Research Mission

A high visibility issue in climate change research is the impact of natural and anthropogenic aerosols on the radiative balance of the planet. One possible strategy for investigating this problem is based on monitoring trends in the global distribution of stratospheric and tropospheric aerosols. Two candidate systematic observation missions listed in Appendix 1 address this objective (measurements of solar occultation by stratospheric aerosol and solar radiation backscatter by tropospheric aerosol).

Nevertheless, the diversity of aerosol origin, composition and optical properties, and the complexity of radiation scattering and absorption by aerosol and ice/water particles are so overwhelming that conclusive findings can only be expected from considerably more sophisticated and penetrating observations. It is essential, in particular, to resolve the vertical layering of aerosol distribution in order to backtrack tropospheric transport and identify the source of the material. The instrument payload that could provide this information would be organized around a backscatter lidar with a range of smaller complementary sensors (polarimeter, multi-directional radiometer, etc.) that could contribute to characterizing the size, shape and optical properties of aerosol and (optically thin) cloud particles.

EX-3: Cloud-Radiation Feedback Research Mission

After water vapor, clouds are the next largest contributors to the planetary greenhouse effect (about 30 Watt/m^2). Altogether, the net radiative impact of clouds on the planetary radiation balance is large (of order of - 20 Watt/m^2) and highly variable. The cloud response to changing climatic conditions is the biggest source of uncertainty in climate model simulations, to say nothing of the essentially unknown indirect radiative forcing of aerosols through the modification of cloud particle size and optical properties. Understanding and modeling cloud processes with adequate accuracy remains the most vexing problem of climate physics, despite decades of research in cloud physics and progress toward explicitly introducing cloud micro-physical processes in specialized "cloud resolving models" and general circulation models. A principal reason is the lack of sufficient (global) observational data to reflect the diversity of weather phenomena and climatic regimes in which clouds are embedded. Understanding cloud-radiation feedback in the context of climate change is the frontier of atmospheric radiation research.

Effective observing tools to resolve the diversity of cloud system geometry and the complexity of cloud optical properties are only now becoming available: backscatter lidar, cloud profiling radar operating in the millimeter wave range, precipitating cloud profiling radar operating in the centimeter wave range, visible, IR and sub-millimeter radiometers or spectrometers. Considering the complexity of the problem and the diversity of observing tools that can shed light on some aspects of the problem, no single cloud-radiation research mission can be singled out as uniquely effective, but several candidate concepts appear thoughtful and scientifically promising.

Any such mission would be organized around a cloud profiling radar and lidar system (the only observing technique that can provide adequate vertical resolution and detect overlapping cloud layers), with complementary passive sensors focused on the same atmospheric column. (The spatial variability of cloud is such that the benefit of multiple sensor observation would be compromised if co-registration was lost.) A **state-of-the-art cloud-radiation feedback research mission** would be a relatively ambitious project, requiring a medium-size spacecraft and a multiple instrument payload (to be determined by selection of one among several comprehensive proposals for mission concept and implementation). This particular experimental mission concept has been studied in depth by at least two partner agencies and would therefore be a good candidate for a joint international cooperative project.

EX-4: Soil Moisture and Ocean Salinity Observing Mission

Soil moisture, a component of ground water storage, is the state variable that represents the terrestrial hydrologic system on time scales relevant to flooding, evapotranspiration and impacts on vegetation (water stress). Soil moisture integrates precipitation and evaporation over periods of days to weeks and introduces a significant element of memory in the atmosphere/land system. There is strong climatological and modeling evidence that the fast recycling of water through evapotranspiration and precipitation is the primary factor in the persistence of dry or wet anomalies over large continental regions during summer. On this account, soil moisture is the most significant boundary condition that controls summer precipitation over the central US and other large mid-latitude continental regions, and essential initial information for seasonal predictions. Precise in situ measurements of soil moisture are available but each value is only representative of a small area.

Remote sensing, if achievable with sufficient accuracy and reliability, would provide truly meaningful wide-area soil wetness or soil moisture data for macroscale hydrological studies and precipitation anomaly prediction over large continental regions. The most mature technique, low-frequency passive microwave radiometry, would also allow the determination of Sea Surface Salinity (SSS). Global surface salinity measurement would provide invaluable information to close the planetary water budget over the oceans and understand the pre-conditioning of surface waters that controls deep water formation in the north Atlantic. The SSS measurement places a challenging requirement on the sensitivity (signal/noise ratio) of spaceborne passive microwave radiometers.

The measurement of soil moisture (and ocean salinity) must still be considered experimental and, for this reason only, was ranked as the second priority of the Hydrology and Global Water Cycle discipline. Developing an effective soil moisture remote sensing system based on passive radiometry requires the deployment of very large antennas (or realization of a correspondingly large synthetic aperture) in order to achieve meaningful spatial resolution (of order ~ 10 km or less) at the relatively low microwave frequencies that can penetrate moderately dense vegetation. The objective of an experimental **soil moisture/ocean surface salinity measurement mission** would be a 3 to 5 year demonstration of an advanced low-frequency dual-polarization passive microwave radiometer or combined active/passive system in low earth orbit (to be determined by selection of competing mission proposals).

EX-5: Time-Dependent Gravity Field Mapping Mission

Measuring the time-varying component of the gravity field is a totally new "remote sensing" approach that provides a unique insight in mass redistribution within the earth system, including climate effects such as ground or surface water storage, and changes in oceanic circulation, as well as tectonic motions and post-glacial rebound. The concept of measuring temporal variations in the gravity field to monitor mass redistribution has already been demonstrated, using various time series of geodetic and gravimetric data. The Earth System Science Pathfinder GRACE mission will extend this proven capability to harmonics above 100. There are strong expectations from both the solid earth science community and global oceanography community that the GRACE mission (to be launched in 2001) will be a pathfinder for a powerful new method to investigate geophysical and geodynamic phenomena.

If this breakthrough is achieved, further technological advances are clearly in sight that will allow at least one order of magnitude improvement in the sensitivity of the method, thus expanding the range of scientific applications. Knowledge of the geoid is a limit to the scientific utility of sea-surface topography data for dynamic oceanography at shorter length scales. Advanced satellite-to-satellite tracking in low Earth orbit would allow significant refinements of the shape of the geoid down to 50-100 km scales, comparable to the scale of ocean eddies and the exploitation of altimetric observations closer to continental margins to characterize coastal currents). In addition, directly detecting changes in total water column mass would allows computing the mean geostrophic flow or Sverdrup circulation.

In view of the fundamental importance of earth gravity data, the oceanic, polar and geodynamic disciplines would place this measurement in their top two or three scientific priorities for long-term systematic observation of fluid and solid earth. On the other hand, the required technology (satellite-to-satellite laser interferometry) is definitely a technical challenge, so that the concept must still be considered experimental. An **experimental mission** would involve launching two essentially identical spacecraft on the same orbit with a single launch vehicle. Operational life time should be a minimum of five years. In view of a broad international interest in space geodesy, this mission would be also a likely candidate for an international cooperative project.

EX-6: Vegetation Recovery Mission

Understanding the carbon cycle is essential to assess future changes in the atmospheric concentration and greenhouse effect of carbon dioxide. A major component of this cycle is net ecosystem productivity in terrestrial temperate and boreal ecosystems, which integrates the regrowth of previously disturbed landscapes, carbon dioxide fertilization, and the result of nitrogen deposition. Quantifying the first of these effects is critical to understanding the response of the carbon cycle to human perturbations.

For this reason, the land cover and terrestrial ecosystems discipline places high priority on a disturbance recovery mission, that could be flown in the late 2000's time frame. The main instrument would be a steerable lidar altimeter system, based on technological evolution of the ESSP Vegetation Canopy Lidar mission (to be launched in year 2000). The purpose of the mission would be to sample the evolution of specific terrestrial biosphere targets that have been subject to major disturbances, like clear-cutting or fires. The scientific objective is to characterize the recovery of above-ground biomass in those areas. A complementary visible-near IR imager could document the recovery of grasslands and semi-arid ecosystems. Altogether this **experimental mission** could be implemented on a small spacecraft and aim for a 3-5 year life time.

X-7: Cold Land Processes Research Mission

Over large regions (e. g. the interior of North America and Eurasia) and high altitude mountainous areas, much of the annual precipitation contributing to streamflow occurs in the form of snow during the winter months. Snow accumulation is a major storage term that strongly impacts the seasonal cycle of runoff. The freeze-thaw status of the soil surface determines the partitioning of precipitation or snowmelt between runoff and infiltration. The high albedo of snow-covered terrain results in large contrasts in net radiation during the thaw period. Important science questions that come to mind are:

- How does the extent of snow and frozen ground affect atmospheric climate?
- Can snow water equivalent be quantified from remote sensing data with sufficient accuracy to improve hydrologic forecast?
- Could these factors be measured accurately enough to identify meaningful climatic trends?

Snow water equivalent and the extent of frozen ground have not been adequately measured from space, due to limitations in spatial resolution of passive microwave instruments and the poor sampling frequency achievable with existing spaceborne imaging radar systems.
A promising, but technically challenging measurement concept is based on applying active SAR imaging techniques at relatively coarse spatial resolution (of order ~ 1 km) to detect freezing conditions on the ground, the extent & amount of snow, and probably various vegetation properties. Coarse resolution could allow a wider swath and short repeat cycle (~ 3 days). This **experimental mission** could be implemented on a dedicated platform in low altitude sun-synchronous orbit. The primary payload would be a 2-polarization, coarse resolution SAR system at L-band or lower frequency. The technical challenge is measuring the intensity of the backscatter signal with much higher accuracy than currently envisaged in high-resolution imaging radar systems.

NASA intends to carefully examine and take advantage of potential commercial and international initiatives in this domain of global SAR observation with high revisit frequency and relatively coarse spatial resolution.

APPENDIX 3

PROTOTYPE OPERATIONAL INSTRUMENT DEVELOPMENT

The Step 1 review highlighted several projects to develop and demonstrate new sensors intended for operational applications as particularly meaningful for scientific research. It has been long recognized that earth system science relies heavily on information and climatological records acquired and archived by operational environmental agencies (for a variety of applications). This is especially true in the field of climatology, as most of what is currently known about the earth climate is derived from the study of weather observation records. Thus, improving the capabilities of operational observing systems (especially polar satellites that provide global coverage) is also essential for the progress of earth system science.

On the other hand, there is currently no established process for identifying joint scientific and application priorities for operational sensor developments, nor for transition from scientific developments to the procurement and accommodation of new operational instruments on operational satellite systems. The development and flight demonstration of specific prototype operational instruments is not explicitly included in the nominal mission plan but could be accommodated by re-ordering flight priorities in the Enterprise's EOS follow-on, Earth Probe and New Millennium programs. NASA is seeking active participation of cognizant user agencies in the definition, development and transition to operational use of new advanced instruments that would meet ESE long-term science objectives as well as operational application requirements. The following is a list (no priority order implied) of instrument concepts that were discussed in the RFI process or otherwise brought to the attention of the Enterprise:

The Workshop generally agreed with this new NASA approach to contributing to the development of new or improved operational observing capabilities. Although no discipline had ranked high-frequency observation from geostationary orbit as their highest scientific priority, there was general recognition of the value of developing a new geostationary sensors for a diversity of research and application objectives. NASA has focused the forthcoming announcement of opportunity for the next New Millennium Program technology demonstration mission precisely to address this objective. NASA is also holding consultations with NOAA/NESDIS on priorities for the development of improved sensors for operational GOES satellites.

OP-1: Advanced Microwave Sounder

The current operational microwave sounder suite, including AMSU-A and MHS, has a total mass of 160 kg. The utilization of new microwave circuit technology would permit substantial weight reduction for the same functionality and the addition or substitution of new microwave channels that would better support the retrieval of precision temperature/moisture soundings in combination with a companion IR sounder. NASA had studied the feasibility of upgrading existing microwave sounders, as part of the Integrated Multispectral Atmospheric Sounder (IMAS) project. Significant progress had been made in the development of microwave technology at the relevant (very high) frequencies and NASA plans to apply these technique to the development of an advanced operational microwave sounder for NPOESS.

OP-2: Tropospheric Wind Sounder

Global measurement of tropospheric wind has been widely heralded as potentially the most significant contribution of satellite remote sensing to existing global meteorological observations (World Weather Watch). Direct measurement of horizontal wind vectors in clear air has been demonstrated using lidar from the ground and from aircraft, based on determination of the wind-induced Doppler shift in the backscatter signal. Two competing techniques are envisaged:

- Coherent detection Doppler lidar system, which is the most sensitive and potentially most accurate technique, but works only in atmospheric layers where sufficient density of scattering particles exists (aerosols). The technique requires development of a unique laser transmitter technology.

- Incoherent detection Doppler lidar system, which is less sensitive but operates uniformly in clear air (works with both Mie scattering from aerosol particles and Rayleigh scattering from air molecules). The technique can utilize a widely used type of laser transmitter.

NASA is preparing a demonstration of the first technique (coherent detection) on a Space Shuttle flight in 2001 (SPARCLE project). There is also private sector interest in developing alternate measurement techniques which could offer the prospect of the availability of tropospheric wind data from a commercial provider.

OP-3: GPS Constellation for Atmospheric Sounding

Measurement of the phase-delay occurring in the propagation of GPS signals near the limb of the atmosphere allows inferring dry air density, temperature and pressure as a function of geopotential height in the region where the concentration of water molecules remains negligible. Below this level, the same technique allows estimating water vapor concentration, provided reasonably accurate temperature information can be obtained from other sources. Altogether, the technique is a completely different approach to atmospheric sounding and would, in principle, provide practically drift-free temperature information throughout the upper troposphere and lower stratosphere, as well as unmatched vertical resolution. Further refinements are also conceivable to extend the domain of application of this and related microwave limb sounding methods.

NASA has made substantial investments in the development of relevant spaceborne GPS receiver technology, as well as software for flight equipment operation and data processing. NASA has also begun to constitute an experimental GPS constellation by furnishing GPS equipment to scientific satellite missions of opportunity developed by international partners. It is expected that this international system will deliver a sufficient number of GPS soundings per day to carry out a meaningful test of the impact of this type of data on the quality of global weather forecast (although only in a delayed or "hindcast" mode).

A further initiative, co-sponsored by UCAR and the Taiwan Academy of Sciences would launch a constellation of 8 dedicated micro-satellites, allowing real-time collection of GPS measurements and delivery of temperature/moisture profile data to weather forecasting centers in time for insertion into the operational analysis and prediction system. NASA is considering possible means to demonstrate this new observing technique.

OP-4: Advanced Geostationary Sounder

One of the two principal sensor on NOAA Geostationary Operational Environmental Satellites (GOES) is an IR atmospheric sounder of relatively conservative design and technology. The sensor allows repeated soundings at very short time intervals over specific regions of interest (where rapid weather development is being observed). However the lack of vertical resolution in the lower and mid-troposphere, where rapid weather development actually occurs, reduces the usefulness of frequent soundings for the purpose of numerical weather prediction. This deficiency could be overcome by a new sounder instrument using state-of-the-art technology (in particular, advanced IR detector arrays and mechanical cryogenic cooling systems). Dynamical meteorology supports the expectation that AIRS-grade temperature and moisture soundings at high spatial and temporal resolution would bring a significant improvement in the ability to forecast mesoscale weather systems and, in general, assist with severe storm warning.

OP-5: Volcanic Ash and Gas Emission Mapping Mission and Advanced Geostationary Earth Imager

The visible and IR imaging radiometer on the current GOES series is a new instrument design that delivers images of the earth disc with unprecedented spatial and temporal resolution. Nevertheless, several improvements are envisaged, such as augmenting the number of spectral channels and further increasing spatial resolution. These upgrades would be justified by a multiplicity of operational applications of geostationary imager data, from tornado warning to fire detection to tracking ash clouds from volcanic eruptions.

OP-6: Special Event Imager

The "Special Event Imager" concept (SEI) is a steerable high-resolution imager that could be pointed to stare at occasional or predictable regional events that vary within a time span of hours rather that days. The SEI is being promoted by the biological oceanography community as well as operational users as a desirable addition to the standard payload of GOES satellites. In addition to numerous applications from wildfire assessments to algal bloom monitoring, the SEI could provide invaluable ocean color change information to capture coastal phenomena that are dependent upon tidal effects.

OP-7: Geostationary Lightning Mapper

Electrical charges that cause lightning strikes are created by rapid ascending air flow associated with strong convective storms. There is evidence that instantaneous mapping of lightning strikes over the disc of the earth from geostationary orbit would enhance the ability to judge the strength of developing storm cells and forecast the likelihood of tornadoes and severe downdraft. The strike rate can also be related in a semi-quantitative manner to convective precipitation. Altogether, a geostationary lightning mapper holds considerable attraction for weather forecasters, but the scientific significance of such observations from one or two geostationary satellites does not match the scientific interest of global lightning distribution data obtained by the NASA-provided lightning detection sensor on TRMM.

Appendix 2
EARTH SCIENCE ENTERPRISE POST-2002 PLANNING WORKSHOP

ATTENDANCE LIST

INTER-DISCIPLINARY REVIEW PANEL

M. Abbott	Oregon State U.
D. Anderson	Applied Physics Lab
T. Alexander	Industry
R. Bras	MIT
R. Brynes	DOI, D.C.
J. Devine	GDIN/USGS
T. Dixon	U. Miami
J. Estes	UCSB
A. Falconer	SSC
C. Field	Carnegie Inst.
E. Frieman	UC San Diego
R. Gagozian	Woods Hole
K. Green	Pacific Meridian
J. Gurka	NOAA/NWS
R. Hallgren	Amer. Met. Society
R. Harriss	Texas A & M
D. Hartmann	U. Washington
M. Keller	USFS
C. Kennel	Scripps
S. Liu	Georgia Tech
M. Molina	M.I.T.
B. Moore III	U. New Hampshire
R. Newell	MIT
J. O'Brien	Florida State U.
D. Peck	USGS
J. Rundle	U. Colorado
H. Shugart	U. Virginia
S. Solomon	Smithsonian
S. Sorooshian	U. Arizona
B. Tapley	U. Texas
R. J. Thompson	EDC
S. Wofsy	Harvard U.
C. Wunsch	MIT

SCIENTIFIC EXPERTS

Atmospheric Chemistry

J. Anderson	Harvard U.
P.K. Bhartia	GSFC
E. Browell	LaRC
M. Gunson	JPL
D. Jacob	Harvard U.
M. Schoeberl	GSFC

Atmospheric Climate & Water Cycle

H. Auman	JPL
C. Birkett	GSFC
B. Davis	U. S. Army Cold Regions Laboratory
G. Emmitt	Simpson Weather Associates, Inc.
D. Entekhabi	MIT
B. Herman	U. of Arizona
T. Jackson	USDA
C. Kummerow	GSFC
E. Smith	Florida State U.
J. Spinhirne	GSFC
F. Wentz	Remote Sensing Systems
B. Wielicki	LaRC
E. Wood	Princeton

Oceanography (including ecosystems) and Polar

T. Liu	JPL
M. Freilich	Oregon State Univ.
J. Zwally	GSFC
W. Esaias	GSFC
C. Vorosmarty	U. New Hampshire
M. Watkins	JPL

Land Cover & Terrestrial Ecosystems

C. Justice	U. Virginia
R. Murphy	GSFC
D. Ojima	Colorado State U.
S. Running	U. Montana
C. Wessman	U. Colorado
D. Williams	GSFC

Geology & Natural Hazards/Applications

R. Adler	GSFC
J. Dickey	JPL
D. Evans	JPL
L. Flynn	U. Hawaii
P. Menzel	NOAA
J. Purdom	NOAA/NESDIS
C. Raymond	JPL

NATIONAL AGENCY and INTERNATIONAL OBSERVERS

US Agency Observers

P. Bryant	FEMA
J. Fein	NSF
D. Goodrich	USGCRP
S. Horrigan	OMB
S. Schneider	NPOESS
R. Winokur	NOAA
G. Withee	NOAA

International Agency Observers

J. Gredel	DLR
F. Guertin	CSA
L. Laurent	CNES
H. Masuko	NASDA
C. Redding	ESA
Y. Sahai	Agencia Espaciais Brazileira
J. Schmetz	EUMETSAT

NASA HEADQUARTERS

G. Asrar
M. Baltuck
R. Bell
J. Campbell
R. Curran
P. DeCola
J. Dodge
K. Herberger
T. Janetos
A. Johnson
R. Kakar
J. Kaye
D. Lettenmaier
E. Lindstrom
M. Luther
N. Maynard
R. McNeal
P. Morel
G. Paules
R. Schiffer
A. Tuyahov
E. Paylor
M.Y. Wei
D. Wickland
C. Wilson

NASA Centers

D. Brannon	Stennis
M. Chahine	JPL
E. Condon	Ames
B. Davis	Stennis
R. Greewood	MSFC
P. Hartley	ESPO
M. King	EOS Project Scientist
G. Komar	GSFC
V. Salomonson	GSFC
S. Smith	GSFC
W. Smith	LaRC

Support Staff

D. Bearden	Aerospace
S. Covington	Aerospace
M. Donnelly	Jorge Scientific
J. Neff	Aerospace
J. O'Leary	Jorge Scientific
S. Sandford	HQ/LaRC

APPENDIX 3: AGENDA

The purpose of the workshop is to review candidate missions and mission scenarios for the period 2002-2010. The overall goal of ESE is to provide systematic measurements of critical earth system parameters and new insight into physical, chemical and biological processes that control the earth climate and global environment. The workshop will be presented with a candidate mission scenario consistent with earth system science and application priorities, and technical feasibility and programmatic constraints. The workshop will be called upon to formulate recommendations to NASA regarding the balance between research disciplines in earth system science, systematic measurements and exploratory research, science-driven programs and technology development or demonstrations.

The workshop agenda will include the following steps:

August 24, 9:00 AM: Program and Science Overview

- ESE overall strategic goals and programs. **G. Asrar**
- Implementation processes and issues: **M. Luther**
- Summary of the RFI process and overview of the nominal mission scenario. **P. Morel**

August 24 PM: Outcome of the Step 1 Review

The Chairpersons of the six Step 1 Review Panels will summarize the emerging Earth system science questions identified in their respective disciplines, and conclusions reached concerning measurement and mission priorities in the next decade.

- Atmospheric Chemistry: **R. McNeal**
- Atmospheric Climate Physics: **R. Curran**
- Global Water Cycle/Hydrology research & applications: **D. Lettenmaier**
- Ocean and Ice research & applications: **E. Lindstrom**
- Land cover and terrestrial ecosystem research & applications: **A. Janetos**
- Solid earth research & applications: **C. Wilson**

August 25 am: **Disciplinary-focus discussions**

Disciplinary groups will review the nominal mission scenario in the light of science (or application) priorities in their respective disciplines and formulate views or recommendations regarding the balance of the nominal mission scenario. Six breakout groups are envisioned:

- Atmospheric chemistry. Chair: **D. Jacobs**
- Atmospheric climate and global water cycle. Chair: **E. Smith**
- Ocean and ice. Chair: **M. Freilich**
- Land cover and terrestrial ecosystem research & applications. Chair: **S. Running**
- Geology, Natural Hazards and Applications. Chair: **M. Baltuck**

August 25 PM: **Report to the Plenary by the Chairpersons of the Disciplinary Groups and general discussion.**

August 26 am: **Executive session of the Interdisciplinary Panel.**

August 26 PM: **Recommendations of the Interdisciplinary Panel to NASA.**

APPENDIX 4: DISCIPLINARY REPORTS

4.1: ATMOSPHERIC CHEMISTRY

Stratospheric Chemistry Missions: A Continuing Strength For The Earth Science Enterprise

Under the Clean Air Act, NASA's charter includes the responsibility for monitoring the stratospheric ozone layer, from space and through in situ measurements. This activity is an important part of the US effort to comply with the Montreal Protocol, and NASA's activity serves policy needs directly through mandated periodic reports on the change in the ozone layer over time and on our scientific understanding of these changes, both anthropogenic and natural.

The primary attributes of stratospheric ozone to be observed are the spatial distribution of ozone and changes over time, both seasonally and over the long term. Total column amounts need to be mapped worldwide with high temporal resolution, in order to detect and quantify phenomena such as the Antarctic ozone "hole" in austral spring, or the thinning of ozone over the Arctic in northern winter. Vertical profiles have to be observed to understand the changes in column amounts and to assess the effects on climate associated with change in ozone. Both of these properties are most effectively measured from space, although requirements of high accuracy, capability for detection of long-term trends, and traceability over very long periods makes this a scientifically challenging task. Hence the assignment of NASA to the job.

In view of the deleterious changes in stratospheric ozone observed in the recent past, attributed to the combined effects of industrial halocarbons, volcanic eruptions, and climate shifts, information data on the controlling factors of stratospheric change is an essential element of a stratospheric research strategy. The most important measurements include temperature, tracers defining transport rates and total turnover time for the stratosphere, aerosol concentrations, and concentrations of critical catalysts for removal of ozone. These observations can be obtained with two sets of space observations, both representing relatively low-cost missions with focused objectives and high payoff, using well-understood techniques.

1. Measurements of ozone and aerosol

Due to the large absorption cross sections for ozone in the near-ultraviolet, visible, and near-infrared, there are several excellent ways to measure ozone total column amounts and vertical profiles.

TOTAL COLUMN MEASUREMENT
We envision a nadir mapping instrument in polar orbit, following on the various TOMS mission and the ozone column mapper on the EOS-CHEM platform. An instrument of this type could fly on NPOESS, however it should be noted that the long-term calibration issue makes this unsuitable for treatment as an operational instrument in the conventional sense.

PROFILES
These data can be obtained readily with an occultation instrument like SAGE-3. The only complexity for this mission is the need for an orbit that provides reasonable scanning of the occultations over a global range of latitudes, at a reasonable frequency.

Due to the nature of the science and policy goals for this mission, particularly the focus on detection of long-term changes, continuity of measurements is a requirement.

2. Stratospheric composition

We envision a low-cost strategy for measurement of a limited suite of species, for example using the FTIR solar occultation sensor selected as an alternate in the first ESSP competition, a relatively low-cost mission with focused objectives and high payoff, using well-understood techniques.

NEW OPPORTUNITIES AND CHALLENGES

The panel identified two major tropospheric chemistry objectives:

- Climate drivers and global climate diagnostics in the near tropopause region and,
- Study of large-scale transport of pollution in the lower troposphere.

3. Upper Troposphere/Lower Stratosphere Mission

In the upper troposphere, temperature, ozone, and water vapor represent critical drivers for global climate. Changes in these parameters near the tropopause can have a disproportionate effect on the radiative forcing of the global climate system. Departures of temperatures in the lowermost stratosphere from radiative equilibrium provide the best measure of stratospheric circulation on a global basis.

Temperature, ozone and water vapor in the upper troposphere, tropopause region, and lower stratosphere are very difficult to measure accurately from the ground or from operational satellites, but can be measured extremely well using new approaches that have been demonstrated, e.g. upper tropospheric water vapor using GPS. We envision a technology development effort to bring to maturity new methods for quantifying these parameters near the tropopause followed by a lean, low cost space mission.

4. Global Pollution Mission

Global-scale pollution has become a major scientific concern and policy issue. It is very difficult to study the transport of pollutants worldwide due to the very long distances involved, cost of large-scale airborne measurements, and political restrictions on sampling. Also, pollution is often confined to relatively thin layers that can be observed optically, but are difficult to quantify with current methods.

Techniques for quantifying global pollution from space have been proposed and some very successful pilot studies have been undertaken in the R &A programs, but the candidate methods clearly need significant technological development to enable a space mission. Possible instruments include space-borne DIAL and UV and IR nadir sounders/mappers. We envision a strong technology development program in this area.

4.2: ATMOSPHERIC PHYSICS, GLOBAL WATER CYCLE AND HYDROLOGY

This is a report of the combined Atmospheric Climate Physics and Global Hydrology panel which met in Easton, Maryland August 25, 1998. The purpose of this panel was to review the nominal mission scenarios presented by the previous panels in light of the science priorities of the disciplines represented. Further, the combined panel was asked to formulate views and make recommendations regarding the balance of the nominal mission scenarios. Finally it was requested of this panel to address the following three questions:

1. Is the nominal mission scenario proceeding from the RFI process **consistent with science objectives and key science questions** formulated by national and international bodies representing the Earth System Science community?

2. Is the **balance between science disciplines** reflected in the nominal mission scenario consistent with emerging frontiers in Earth System Science?

3. Does the balance in the nominal scenario between **systematic measurement and discovery or process – oriented** research missions reflect an effective strategy for addressing key science questions in Earth System Science?

Overview – General Comments

A total of nine mission scenarios were presented in the plenary session by the chairs of the two previous discipline panels. The panel in Easton did not add or remove any of the nine scenarios.

The general responses by the panel to the three questions asked were as follows:

1. The key science questions being addressed by each of the scenarios were considered to be well articulated, the scenarios were consistent with the science questions asked, and each was traceable to questions identified by national and international bodies representing the Earth Science community.

2. There was reasonable balance and notably strong synergism between the two science disciplines represented in this panel.

3. The panel was comfortable with the mixture of systematic and exploratory missions. Furthermore, the panel recommended that the balanced mix of systematic and exploratory missions not be altered by subsequent review bodies.

Mission Concepts – Atmospheric Physics

The RFI Atmospheric Climate Physics Panel identified and prioritized the following mission scenarios:

Priority	Science Question	Mission Type	Priority Justification
1 (i)	Aerosol-Radiative Forcing-Feedback	Exploratory	Of all the radiative forcing processes affecting climate, aerosols have the largest uncertainty in the magnitude of their contribution and their spatial and temporal dependence. Global measurements of aerosol optical properties require an extraordinary complement of dedicated space-borne remote sensing instruments.
2 (i)	Cloud-Radiative Forcing-Feedback	Exploratory	The magnitude of cloud radiative forcing of climate is second only to water vapor. Dramatic changes in cloud radiative feedback are governed by subtle changes in the environment including aerosols. A dedicated space-borne mission including active and passive sensors is required.
3 (ii)	Variability and Trends in Basic Climate Variables	Systematic	During the period of time following EOS PM-1 and prior to NPOESS, a continuation of space-borne measurements of atmospheric temperature, moisture and TOA radiation fluxes is required.
4	Variability in Solar Forcing	Systematic	During the period of time between TSIM and NPOESS, continuation of space-borne measurements of solar irradiance is required. Reasonable overlap between successive missions must be scheduled to allow degradation checks on instrument absolute calibration.

All four missions were given equal priority and equal urgency.

Two final summary comments were expressed (relative to their identification in the priority column):

(i) There is strong synergism between the Aerosol- and Cloud-Radiative Forcing-Feedback Missions in terms of various of the required instruments.

(ii) Although costly, and possibly technologically challenging, the Lidar-based tropospheric wind sounder should be considered as part of the Climate Variability Mission (#3 in Atmospheric Climate Physics).

Mission Concepts – Hydrology and Global Water Cycle

The RFI Hydrology and Global Water Cycle Panel identified and prioritized the following mission scenarios:

Priority	Science Question	Mission Type	Priority Justification
1 (i, ii)	Global Precipitation Measurement	Systematic	Precipitation is the primary forcing variable in modeling land surface hydrology and in determining diabatic heating of the troposphere. Major advances beyond TRMM are now possible in monitoring the diurnal cycle of rainfall at high resolution (10 km - 3 hour) by using a satellite constellation consisting of a calibration quality "Mother" satellite plus 6-8 small drones.
2 (iii)	Soil Moisture Measurement	Exploratory	Soil moisture is the primary state variable in the land hydrological cycle. This measurement has a variety of important new applications in hydrological modeling, mid- to long-range numerical weather prediction, climate assessment and modeling, crop modeling, and terrestrial ecology.
3 (iv)	Mesoscale Weather	*Adjunct Operational*	Mesoscale weather systems are the fundamental atmospheric building blocks of climate and climate variability. From a process perspective, they require measurements at high space resolution over the diurnal cycle at numerous optical, infrared, and microwave spectra. From a monitoring perspective, they require flexible full-disk coverage at both imaging and sounding wavelengths.
4	Surface Water Measurement	Exploratory	This mission is focused on measuring lake and river level heights as a means to estimate river discharge at both continental scales and river basin scales. This measurement would provide a primary closure parameter for hydrological models, and would provide valuable input for monitoring the water quality of coastal water systems.
5	Cold Processes Research	Exploratory	Accurate measurements of snow cover, snow depth, and snow-water equivalence at high latitudes is required to understand seasonal snow variability and its feedback on global climate change.

The Global Precipitation Measurement Mission was given highest priority for a systematic mission, due to the need for continuation of the quantitative satellite rainfall time series which began in mid-1987 with the launch of the first SSM/I and presently extends through the launch in November-1997 of the Tropical Rainfall Measuring Mission (TRMM). The Soil Moisture Measurement Mission was given highest priority for an exploratory mission, an experiment which would provide the first global dataset of the fundamental state parameter in the land hydrological cycle.

Four final summary comments were expressed (relative to their identification in the priority column of the hydrology and global water cycle panel):

(i) The Global Precipitation Measurement Mission (#1 in Global Hydrology) should be **moved up to the 2003 time frame** since the TRMM Follow-on Mission designated for that time frame and described in the report *ESE Mission Scenario for the 2002-2010 Period*, (identified as the International Precipitation Mission) is now a non-starter based on recent decisions within NASA and NASDA (Japan).

(ii) The strong synergism in required measurements between the Global Precipitation Measurement and Cloud-Radiative Forcing-Feedback Missions suggests that they should be considered for implementation in the same time frame, under a shared instrument program.

(iii) Although there is the strong possibility that a radiometer suitable for soil moisture measurement could, with some additional technological improvement, also provide ocean salinity measurements, a soil moisture mission should not be held back to wait for the technology to "catch up" to the requirements for measuring salinity. This is fundamentally an issue of sensitivity, in which soil moisture is the "easy" measurement because it produces a very large signal in brightness temperature, whereas ocean salinity is the "difficult" measurement because it first requires separating thermometric temperature from emissivity, with the latter representing the signature for salt concentration only after other sources of emissivity variation are removed (temperature, roughness, phytoplankton concentration, effluent concentration).

(iv) There is a need for identifying another mission category for the Mesoscale Mission scenario (#3 in Global Hydrology). This category may be considered to be a new ***Operational Adjunct Mission*** category. This mission requires the development of an **Advanced Geostationary Spacecraft** program, and will require more focused science objectives which could result from the phase-A design.

4.3: OCEANS AND ICE

The Oceans and Ice group briefly examined and endorsed the overall scientific foci of the Step 1 report. The oceans and polar ice regions play critical roles in the Earth system and climate. The oceans provide thermal inertia and upper ocean processes account for more than half of the Earth's poleward meridional heat transport. The oceans are sinks and sources for key compounds in global biogeochemical cycles; primary oceanic productivity is a major factor in the global carbon cycle and a governing factor in atmospheric CO_2 balance, and ocean productivity (especially in coastal zones) fundamentally limits fish harvests and related direct societal exploitation of ocean biological resources.

Sea-ice substantially modifies the surface thermodynamic properties of polar regions, changing the surface albedo, thermally insulating the ocean from the overlying atmosphere, and resulting in important regional circulation perturbations in both the oceans and the atmosphere. Ice formation processes and brine rejection play controlling roles in the formation of deep water and the fresh water balance of the upper ocean. The composition, volume, and temporal evolution of polar ice sheets is a sensitive indicator of interannual climate change and is closely related to interdecadal regional and global sea level changes.

The group noted that space-based measurement approaches for most of the critical dynamic, thermodynamic, and biogeochemical ocean and polar ice variables have been demonstrated and their accuracy quantified (sea-surface salinity is presently an exception.) In the first-series EOS period, simultaneous global time series with appropriate accuracy, spatial and temporal resolution, coverage, and stability will be established or continued for the highest priority variables: sea-surface topography and upper ocean currents, surface wind forcing, ocean color and productivity, polar altimetry, and gravity. It is assumed throughout that clear-sky (cloud-free) measurements of sea-surface temperature will continue to be acquired with at least the present accuracy, resolution, and coverage, by U.S. and international instruments on operational polar-orbiting spacecraft, as at present, throughout the first decade of the next century and beyond.

The multiplicity of energetic oceanic temporal and spatial scales require that measurements resolve the smallest scales in order to avoid aliasing small-scale variability into the large-scale climate signals of interest. Likewise, the known nonlinear coupling of oceanic scales for upper ocean wind driven circulation, and the intimate dependence of shorter temporal and spatial scale ocean productivity variability on similar small scale variations in the upper ocean's physical state, require modeling and measurement of small scales to achieve accurate large-scale climate predictions. Fortunately, the smaller-scale data thus acquired are vitally useful both for operational prediction (as in the case of mesoscale and coastal upper-ocean circulation, numerical weather prediction using surface vector wind measurements, and fishery harvest location) and for detailed process studies that may lead to more accurate parameterizations of small-scale variability, and thus more tractable climate models.

Given the agreement on the pressing ocean and polar ice science issues, the known capabilities of the remote sensing measurement techniques for most of the key quantities, the planned initiation of multi-decadal data sets with appropriate accuracy, resolution, and coverage during the early-EOS period, and the clear prioritization of measurement importance provided by the Step 1 Panel, the Oceans and Ice breakout group focused on an analysis of the mission recommendations provided by the Step 1 Panel and the subsequent NASA nominal mission scenario. For each of the 7 oceans and ice missions recommended by the Step 1 Panel, the group addressed the following questions:

(1) Is the nominal mission scenario consistent with key scientific questions and objectives formulated by national and international bodies?

(2) Is the scenario consistent with the goal of forming strong partnerships with other national and international agencies, and with commercial firms?

(3) Is the nominal mission scenario consistent with a responsible transition to operational data acquisition, ensuring that measurements planned to be acquired under the auspices of operational missions and agencies will meet the present science requirements of the NASA climate community and allow for construction of consistent, multi-decadal, data sets?

(4) Is the nominal mission scenario ("blue book") consistent with the recommendations emerging from the Step 1 Panel ("white book")?

Here we present for each mission, in priority order, a summary of the group's conclusions and recommendations.

1. Ocean Altimetry

Findings: The Step 1 Panel regarded long-term continuity of TOPEX/Poseidon class sea-surface topography measurements as the highest priority. According to the nominal scenario, altimetry measurements will be acquired from an instrument onboard the operational polar orbiting spacecraft in the NPOESS era. There are no definite plans for a NASA mission beyond Jason 1. Hence it is probable that there will be a gap between Jason 1 (launched in 2000) and the beginning of the NPOESS measurements series beginning in 2009. There was a promise to "explore partnering" to acquire ocean altimetry measurements after Jason 1, but this was not well defined.

Recommendations:

- As noted above, no gap can be scientifically justified; the time scales of cross-basin information transfer through the ocean (primarily through planetary waves) *are* the climate time scales. The measurement of sea-surface topography is the single most effective way of detecting interannual climate variability, yet, owing to the presence of energetic small-scale, high-frequency variability, any significant gap in the data set significantly degrades the scientific utility and value of the entire, multi-mission time series.
- Data quality and continuity should be of paramount importance. It is insufficient to ensure a high quality instrument if that instrument is flown in the wrong orbit. NASA should assure that future scenarios provide data of similar scientific value to that provided by TOPEX/Poseidon and Jason 1.
- A study should be conducted to determine whether altimetry acquired from an 800-km sun-synchronous orbit will meet requirements. The panel expressed concerns related to tidal aliasing, precise orbit determination, sampling, and knowledge of the geoid.
- NASA must pay particular attention to the challenges associated with transitioning high-quality continuous measurements to operational agencies.

2. Vector Wind Measurements

Findings: The Step 1 Panel regarded long-term continuity of adequately sampled, SeaWinds-quality vector winds as the second highest priority mission. However, the nominal mission scenario shows no plans for NASA to continue SeaWinds measurements beyond the scatterometer onboard ADEOS-2. The nominal scenario calls for METOP to provide vector winds after ADEOS-2, and a transition to reliance on passive microwave instruments for vector wind measurements during the NPOESS era.

Recommendations:

- Data quality, including accuracy, resolution, coverage and continuity should be of paramount importance.
- Based on analyses conducted at GSFC (Robert Atlas) and coverage/resolution/accuracy requirements generated by NOAA/NCEP (Helen Woods, personal communication), the planned single scatterometer to fly onboard METOP alone will not be adequate to meet NOAA/NCEP operational needs. This instrument has narrower swaths, and lower spatial resolution, than NSCAT provided (SeaWinds continuous swath allows significantly greater coverage with high spatial resolution). Multiple, simultaneous, polar-orbiting, all-weather vector wind instruments are required to allow measurement of synoptic surface wind features and to allow construction of accurate, gridded, basin-scale fields resolving spatial scales of a few degrees and temporal scales of 2-3 days, without excessive reliance on atmospheric circulation models of dubious accuracy in the surface layer.
- Given that there are significant risks associated with the passive, polarimetric approach planned for NPOESS, NASA should develop a plan for managing this transition so that the investment in SeaWinds-class measurements is not lost.
- NASA should fly a SeaWinds follow-on mission to bridge the gap between ADEOS-2 and NPOESS. This is a prudent approach that would provide time to evaluate capability of the passive techniques.

3. Ocean Color Measurements

Findings: The Step 1 Panel regarded long-term continuity of ocean color measurements as the third highest priority mission. The nominal scenario calls for a gap-filling mission as a bridge between MODIS and the visible and infrared sensor (VIIRSS) on NPOESS. The instrument proposed is the Advanced Global Imager (AGI). This instrument will provide adequate baseline measurements consistent with the time series begun in 1997 with SeaWiFS, but it will not have the full capabilities expected from MODIS. The proposed gap-filling mission will be in a morning orbit.

Recommendations:

- Data quality (accuracy, resolution, coverage and continuity) should be of paramount importance. Again, this requires not only a high quality instrument, but consideration given to the orbit characteristics, local sampling time, and other aspects (e.g., sensor tilt, etc.).
- The AGI should have a science team to guide the full mission design and evaluate the science capability of the mission and the utility of the data.
- Calibrated spectral radiance should be one of the "environmental data records" (EDRs) delivered by the AGI.
- Continuity of ocean color measurements during the bridging mission and the NPOESS era requires either one tilting sensor (to avoid sun-glint), or two non-tilting sensors with equatorial crossings within 1.5 hours of noon.

4. Comprehensive Ocean/Air Interface Mission

Findings: This was recommended as the 4th priority (overall) and the highest priority experimental mission by the Step 1 panel. The original mission concept called for a suite of measurements made by a single instrument. The nominal scenario called for a mission focusing on salinity and soil moisture. It was also considered experimental in the nominal scenario.

Recommendations:

- This is a high priority experimental mission with substantial technological challenges but very high payoff if salinity measurements with accuracy of 0.1 to 0.3 PSU can be achieved.
- The announcement of opportunity (AO) soliciting proposals for a salinity mission/instrument should provide flexibility to include other ancillary measurements which can be made with the same instrument for modest additional cost.

5. Polar Altimetry Mission

Findings: The science objectives of this mission address questions of the mass balance, kinematics, and climate sensitivity of polar ice sheets. Measurements made with this instrument have broad applications, including potential measurement of major continental river stages and lake levels.. The nominal scenario calls for Polar Altimetry to be a systematic measurement beginning with ICESat in 2001, and with a follow-on ICESat -like mission in 2010. Following this scenario, there is likely to be a 5-year gap in the measurements.

Recommendation:

- The significant energetic scales of polar ice variability are not well quantified, yet the sensitivity of polar ice mass balance to climate state is high. A study should be conducted to determine whether a 5-year gap is acceptable or whether a strong scientific justification can be made to minimize or eliminate the gap.

6. Gravity Mission

Findings: The nominal scenario considers a proposed follow-on to GRACE with higher spatial resolution as a potential experimental mission.

Recommendation:

- This mission should continue to be regarded as a potential experimental mission. Any future announcement of opportunity should be based on what is demonstrated by the GRACE mission. This mission can contribute to improved information on the geoid (of benefit to both radar and laser altimetry missions), and ocean bottom pressure with 100-200 km resolution.

7. Special Events Imager

Findings: This pointable imager proposed for a geostationary satellite would provide unique ocean color images with high temporal resolution (a full scene every 10 minutes) to allow the investigation of tidal effects on coastal ecosystems. The nominal scenario regards this as an "operational prototype" instrument. As such, before NASA would agree to build such an instrument, there would have to be a firm written commitment on the part of NOAA to fly the instrument. NOAA has expressed a willingness to fly this instrument on GOES N, but the decision for NASA to build this "operational prototype" for GOES N must be made within the next 3-4 months. There was a strong advocacy for this instrument on the part of "applications-oriented" participants during the Step 1 Panel review.

Recommendations:

- The potential ocean science contributions of this instrument are endorsed.
- NASA should continue to explore the attractive near-term opportunity to fly this instrument on GOES N.
- The group strongly urges NASA to rebuild programmatic links with NOAA to allow for near-term and future collaborations.

8. Advanced Ocean Color Mission

Findings: This instrument was not one of the 7 missions recommended by the Step 1 Panel because it was believed (mistakenly) that it requires a hyperspectral sensor. The Advanced Ocean Color Mission proposed a sensor with high radiometric sensitivity (high signal to noise) for measuring chlorophyll fluorescence in addition to the more standard chlorophyll pigment. This would be a follow-on to the MODIS capability of measuring fluorescence, and is expected to provide valuable information on ecological impacts of climate change.

Recommendations:

- Ocean productivity derived from measurements of chlorophyll fluorescence with high signal-to-noise and modest spectral resolution should be one of the potential experimental missions that NASA considers.

- The group does not recommend a hyperspectral ocean color imager. (This decision should be revisited after the Navy's NEMO satellite has flown and demonstrated the value of hyperspectral data).

4.4: SOLID EARTH, NATURAL HAZARDS AND APPLICATIONS

The breakout disciplinary panel on Solid Earth/Natural Hazards/Applications (hereafter called the Panel) considered the mission concept selection and recommendations prepared by the RFI review, compared these recommendations with corresponding entries in the "Mission Scenario for the 2002-2010 Period" and made several additional comments. The following sections summarize these discussions:

1. RFI Review

The RFI review identified 6 mission concepts in three separate categories. The three categories, geopotential fields, topography and surface change, and natural hazards and applications, were not ranked by the RFI review panelists. However, they did assign first and second priorities to the two recommended missions within each of the 3 categories as follows: **Geopotential Fields Category**: 1. Temporal Variation of Gravity Field and 2. Magnetic Field Missions; **Topography and Surface Change Category**: 1. InSAR Surface Deformation and 2. High resolution topography missions; **Natural hazards and Applications Category: 1.** Volcano and 2. Severe Storms Research Missions.

This list was endorsed by the Panel, although the Panel noted that in the category of natural hazards and applications, the listed missions were not comprehensive. The need for a more comprehensive assessment of natural hazards aspects of all missions is addressed later in the recommendations.

2. Blue Book Comparison with the Outcome of the RFI Review

The following summarizes the discussion of mission proposals within each of the three categories. Again, there was no attempt to assign priorities to the three separate categories of geopotential fields, topography and surface change, and natural hazards.

Geopotential Fields

a. Gravity mission

The panel was pleased to see the mission had survived the transition from White Book to Blue Book, and that the synergy with the recommendations of the Ocean & Ice Panel remained an important driver for the mission. However, the panel recommended that the GRACE follow-on mission be placed in the ‘systematic’ category, due to the value of continuous long-term measurements of temporal gravity field changes. Observations begun with GRACE should be continued for a decade or more, due to their unique ability to measure mass redistribution of water on a variety of time scales.

b. Magnetic Mission

The panel was disappointed to see that, although there were words in the Blue Book endorsing the scientific value of continued magnetic field observations, there was no mission listed in the Blue Book. A continued series of observations, past the year 2005 through which observations are now planned, is important for the understanding of the Earth’s magnetic dynamo in the core. The panel recommends that NASA pursue active partnerships with foreign scientists and Code S, using Code Y research program resources as required, to continue the magnetic field observations. This would effectively continue the strategy that has yielded the current suite of missions (Oersted with Denmark; SUNSAT with South Africa; CHAMP with Germany; SAC-C with Argentina)

Topography and Surface Change

The EOS class missions listed in the Blue Book contained some of the recommendations from the White Book, but the Panel felt that they did not accurately reflect the White Book discussion. Clarification of the motivation for two separate efforts - one for surface change, the other for high resolution topography - is contained in the next paragraphs. Another point not emphasized in the Blue Book is the possibility for synergy between surface change Interferometric SAR missions and missions related to land cover, soil moisture, and other quantities (EX-4, EX-6). Synergy may also be possible between the high resolution topography mission in the White Book (which did not make it to the Blue Book) and proposed hydrology (river stage, as recommended by the Easton Panel) and polar ice mapping missions (EOS-10) which would employ laser altimeters. The Panel also noted that there may be value in a reflight of the SRTM mission in several years after the initial late 1999 flight. This reflight could address some surface change and higher resolution topography needs, and be conducted in partnership with NIMA.

Repeat pass Synthetic Aperture Radar (SAR) mapping of the land and ice surface will make important contributions to the land cover and natural hazards communities via all weather images, high resolution topography, and surface change. Emerging interest in natural hazard reduction, and recognition of the high value of repeated all weather coverage afforded by this sensor, provides a strong incentive to maintain essentially continuous SAR coverage of the globe. At the same time, requirements for extremely high accuracy topographic data in selected areas implies the need for augmentation of the InSAR data set by other approaches, as outlined below.

a. InSAR Surface Deformation

Interferometric SAR (InSAR) is the best way to measure subtle land surface change and ice velocity on a global basis. The complete global coverage, high spatial resolution, and high accuracy of surface displacement measurements from InSAR is unprecedented-the solid earth science community has never had a data set like this at its disposal: it is simply not possible to obtain analogous data by any other means. A dedicated InSAR mission has the potential to revolutionize our understanding of the behavior of the earth's upper crust. A two satellite L-band InSAR mission is probably the best approach. While each satellite can independently perform repeat pass interferometry, if each satellite is in a different orbit, three component vector displacement data can be obtained in areas of joint coverage. A mission with an international partner providing the second satellite may be an attractive option. This mission can also provide global topographic data with a resolution exceeding SRTM.

b. High resolution topography

Higher precision topographic data in selected areas can be pursued by other means. A follow on ICESat (laser altimeter) mission is necessary for ice change estimates (see EOS-10) and could provide some data at mid and equatorial latitudes. Other technologies (scanning lasers, beam limited radars), including aircraft platforms, should also be investigated, possibly in collaboration with commercial partners.

Natural hazards and Applications

Volcano and Severe Storms Research Missions appearing in the White Book represent applications of a variety of sensors which have scientific research value and the potential for eventual operational deployment. The panel examined the list of prototype operational missions in Appendix 3 of the Blue Book, and noted that many of these included sensors which had important natural hazard applications, including volcano and severe storms applications called out in the White Book.

The Panel strongly recommended a *research geostationary platform*, perhaps via a specific announcement of opportunity, for scientific research on processes that require nearly continuous time sampling, and to demonstrate the applications to a variety of natural hazards.

The panel recommends that all proposed missions be examined for their application to natural hazards research and applications. This task was not accomplished at the Easton meeting because the membership of the panel did not necessarily represent the required breadth of disciplines, and the task was not assigned to the panel. At the Easton meeting, other panels did discuss natural hazard applications (for example hydrology discussed applications to floods and drought), but there was no organized effort among all the panels to cover the full range of hazards that can be addressed from space-based observations. Such a review of natural hazards applications should be included as a step in the mission planning process.

3. Other Recommendations

The Panel felt that the three Blue Book mission categories (EOS-type, Experimental, and Prototype Operational) were too restrictive, although they may be useful for budget planning purposes. For example, the three categories do not represent the wide variety in mission costs, the need for continued observations of some quantities, (such as gravity, classified as Experimental) and the possibilities for reducing costs of certain missions by working with international partners.

The Panel recommends that NASA's mission plans specifically call out the value of ground systems in the solid earth and natural hazards area (an example is ground-based permanent GPS networks which complement Interferometric SAR measurements of surface deformation).

Another important point to be called out in a mission strategy is the need for aircraft campaigns to develop instrumentation prototypes, and to complement space missions in the study of processes which require extremely high spatial resolution. (An example is coastal processes and coastal topography).

While the planning nominally involves 'missions' the value of numerical modeling activities must be emphasized in a comprehensive mission plan, as well.

In terms of timing, technology development should be undertaken after considering missions beyond the time scale considered by the Blue Book. Consideration also needs to be given for use of other platforms, including small Shuttle (GAS can/hitchhiker missions) and Space Station missions.

Finally, if the recommendations made here are accepted, then the Panel feels that a reasonable balance of missions is present in the suite of missions.

4.5: LAND COVER AND TERRESTRIAL ECOLOGY RESEARCH AND APPLICATIONS

Science Questions

The Land Cover and Terrestrial Ecology Research and Applications (LC/TE) breakout group discussed the proposed carbon cycle focus for the post-2000 mission concepts. The group thought that the carbon cycle questions represented an important and timely focus for future missions in this disciplinary area and represented a good start for shaping future science and applications missions, but emphasized that there are other aspects of ecosystem structure and function that are equally important to know about (e.g., terrestrial biogeochemistry, trace gas fluxes, biodiversity, and ecosystems goods and services) -- and that can be addressed by the same, or slightly modified, mission scenarios that were proposed.

It was pointed out that the future sustainability of the planet, which is directly tied to the carbon cycle focus, is a goal equally worthy of consideration for focusing future missions. This, and other applications research objectives could and should be more tightly woven into NASA's rationale for future missions. There are strong links among science, sustainability, and resource management.

The RFI process led to formulating three major scientific questions that can be addressed with remote sensing data:

1. Understanding the rates and locations of land-cover change, sampled at appropriate spatial and temporal scales (the "accounting problem").
2. Understanding the processes associated with biological productivity.
3. Understanding the rates and degree to which landscapes recover from both anthropogenic and natural disturbances.

Scientific questions # 1 and #3 are related and may not need to be distinguished as separate themes. Both involve monitoring and assessment of landscapes that are changing rapidly due to extensive and intensified land use and natural disturbance regimes.

The group wanted to make it very clear that the carbon cycle research must emphasize understanding processes and the environmental controls on elements of the carbon cycle, not just on developing better carbon budgets. The group felt that the RFI panel review report did not sufficiently address respiration and carbon allocation within ecosystems as related to understanding processes controlling net ecosystem carbon exchange in its discussion of the carbon cycle. The recommended "ecosystem recovery from disturbance" mission, in particular, offers an excellent opportunity to delve into these aspects of the carbon cycle if spatial pattern and vegetation structure (e.g., major growth forms, vegetation size classes, vegetation composition, partitioning of carbon into live, dead, and soil components) can be made a stronger emphasis for the mission. This also would enable a very desirable expansion of the scope of that mission to cover important scientific issues related to biogeochemical processes and landscape spatial patterns (e.g., habitat fragmentation and biodiversity) that are not directly related to the carbon cycle. An ability to acquire targeted hyperspatial data (~ 1 m) would be a critical additional requirement for these scientific applications. The group suggested that references to ecosystem "recovery" should be replaced with "response" to avoid suggesting ecosystems are currently in equilibrium and would be expected to return to their original state following a disturbance.

Most ecological and land cover-related questions are not likely to be solved with a single-sensor approach. In some cases, this means using supporting data from other satellite missions. For example, to attack the question of biological productivity (scientific question #2), land surface hydrological and meteorological data (e.g., temperature, humidity, precipitation) and physical oceanographic and atmospheric data (e.g., sea surface temperature, ocean circulation, surface winds) are needed. These and other such connections to related disciplines and missions need to be explicit in NASA's mission plans. In other cases, multi-sensor approaches on a single or multiple platforms may need to be considered. In addition, data from *in situ* sensors and monitoring networks will be needed. An integrated observational strategy is what is needed and should be recognized by the NASA program.

Although the focus of this breakout discussion was on the development of targeted space missions as elaborated in the mission concepts review summary (white paper) and mission scenario for the 2002-2010 period (blue book), concern was voiced regarding the lack of integration and the discipline-oriented missions that were defined in the current process. There is a need for cross-disciplinary approaches to better resolve certain issues, especially issues regarding ecosystems. Because of the complexity of biosphere interactions with the climate, hydrosphere, and human activities, a multiplicity of approaches and remote sensing techniques needs to be employed.

The presentation for the plenary session added a brief discussion of time scales and the processes that must be captured in order to understand the global carbon cycle. Intra-annual information on phenological dynamics and land use is imperative to detect vegetation response to interannual climate variability and directional change. On seasonal time scales, carbon fluxes can vary greatly due to disturbance, resource availability affected by intra-annual variability in weather, and growing season length. Moreover, at decadal to century time scales, biomass and net primary productivity increase non-linearly following disturbance and can "re-set" to a low value at any time following another disturbance. Coupling seasonal dynamics and disturbance history at regional and global scales is part of the challenge both for the land cover inventory and the response from disturbance missions. These two missions, in close coordination with the productivity mission, will contribute substantially to our understanding of the human and ecological controls on carbon cycling processes.

The importance of spatial pattern on the landscape and the spatial pattern of disturbance was also highlighted in the plenary session. Spatial arrangement and the temporal sequence of disturbances matter.

Recommendations

- Major scientific issues #1 and #3 in the RFI panel review report should be re-written to include "patterns" and to replace "recovery from" with "response to".
- The underlying science behind science question #3 (disturbance) should be expanded to include spatial pattern as described above.

The revised major science issues are listed in Table 1.

TABLE 1

MAJOR SCIENTIFIC ISSUES FOR
LAND COVER/LAND-USE CHANGE AND TERRESTRIAL ECOLOGY

Understanding the rates, patterns, and locations of land-cover change, sampled at appropriate spatial and temporal scales (the "accounting problem")
Understanding the processes associated with biological productivity ("productivity")
Understanding the rates, patterns, and degree to which landscapes respond to both anthropogenic and natural disturbance ("disturbance")

Science Mission Implementation

Global Land Cover Inventory Mission

This mission is a high priority to maintain the continuity of the Landsat data stream and the science and applications work that it supports. The group spent some time discussing the current lack in the U.S. of a national commitment to a long-term implementation strategy for such data. This appears to be an obvious missing component of NPOESS -- there would be enormous synergy in flying the coarse and fine resolution MODIS-type and Landsat-type imagers together. What is the U.S. plan/policy? This is an issue that ought to be worked at the highest levels across the U.S. Government. The group did not know how to assess the feasibility of a private sector source for global land cover inventory data in 2005 as was suggested in the "blue book." They thought that another option that must be considered is for other government agencies to champion certain types of long-term operational measurements as central their missions. The Department of Interior was mentioned as a possibility in the land cover arena.

It was suggested that a land cover inventory mission could benefit from radar data -- in particular, to acquire data in regions of high cloud cover, but also to provide unique remote sensing information such surface wetness/inundation conditions for wetlands cover types.

Data handling issues related to efficient, timely processing and information extraction from this high volume data stream were noted as challenges to the success of this continuing mission for global land cover.

The group noted that repeat coverage that is more frequent than every 16 days would be highly desirable.

Global Ecosystem Productivity Mission

This mission is a critically needed gap filler to ensure the continuity of the AVHRR --> MODIS data stream to the time that NPOESS flies with the planned VIIRS. Initial discussion of this mission concept centered around the unresolved issues of orbit crossing times. There will be a gap in the PM series after PM-1 and before NPOESS -- this is less critical to the core LC/TE objectives. At present, if METOP cannot fly a VIIRS-type instrument (due to size constraints), the AM series of observations ends in 2009 after the gap filler mission. This is a serious issue for LC/TE because the AM orbit offers the optimal viewing conditions for the land surface. This was flagged as an issue for NASA attention and work toward resolution.

The group discussed the pros and cons of implementing this mission with an early copy of the VIIRS instrument. They noted that there would be loss in capability over MODIS -- e.g., fewer channels, less rigorous calibration. They welcomed the opportunity to fill the gap in systematic observations with a relatively inexpensive implementation so that resources could be freed for the exciting exploratory missions being considered. One critical dimension to a successful VIIRS implementation would be to ensure that NASA scientists could have full visibility into the instrument and algorithm development process with the opportunity to influence it through scientific peer review. Identification of a science team for this mission as soon as is possible would be a good idea. Even if this implementation option for the gap filler is not pursued, the scientific community would still have to work hard to ensure that the future NPOESS data stream will do the basic job for ecosystem productivity. The focus must be on getting our most basic requirement filled through the operational data stream.

There was a brief discussion of the possibility of addressing this gap filler mission through foreign sensors (MERIS follow-on or GLI follow-on). However, no one knew very much about ESA or NASDA plans for such missions in the 2005 time-frame, and, in fact, several thought that such plans did not exist. Exploring this idea will have to be a homework activity to follow this workshop, and implementing it would require a much higher level of international coordination than we have at present.

Ecosystem Response to Disturbance Mission

The scientific requirements for a “biomass recovery” mission seem most clear. However, the scientific focus for this mission should be expanded to encompass “developing an understanding of ecosystem and landscape dynamics at pertinent management and disturbance scales”. The idea that this will be a sampling mission with targetable, periodic revisit capability is appropriate. Targeting capability will be critical.

The required frequency of repeat observations is fairly well-defined for biomass recovery, but less so for management and disturbance dynamics and biodiversity, fragmentation, and spatial pattern issues. Frequent sampling within the growing season will be needed to capture structural changes related to biomass recovery and response to disturbance intensity. This periodicity will likely satisfy the sampling requirements for some of the other issues as well (such as fragmentation), but sampling schemes for them need to be developed in the near future.

This mission will be relevant to looking for climate change responses in ecosystems -- at least those which can be discerned over the course of a few years. It also will be able to observe physiological changes which are manifest over the course of a growing season. The approach for getting at these dynamics needs refinement. Investigation of seasonal structural dynamics to get at dynamics in allocation and respiration should be considered as well, but will require a combination of *in situ* observations, process studies, and modeling for successful resolution.

The technological implementation for this mission needs further careful study. Lidar is promising, but, at least as implemented for the VCL mission, it never gives a local canopy profile -- it only delivers averages. It may be at too coarse a scale for many of the spatial questions. It is possible that combining lidar data with hyperspatial data might at least in part resolve this problem. Experiments could be conducted now using airborne sensors, or perhaps a Shuttle experiment, to look at various spatial footprints in different biomes to try to sort out this issue.

The group introduced and emphasized the importance of hyperspatial observations to this mission concept. Fulfilling the requirement for hyperspatial data was initially discussed in the context of a potential commercial data buy. As the meeting progressed, the value of accurate co-registration of hyperspatial data with coarser resolution multispectral data to unravel sub-pixel information on processes and structure was stressed. The group recommended that accurate co-registration of the hyperspatial and coarse spatial resolution data be an important requirement for this mission and that NASA weigh carefully the pros and cons of adding a hyperspatial channel to a planned multispectral instrument versus buying a commercial hyperspatial data set.

Other technologies that have potential to equally well address some of the observational objectives of this mission include multi-angle (as in MISR), SAR, and hyperspectral remote sensing. Further study will be required before an optimal choice of technologies for measurements can be recommended. The requirement for atmospheric correction in any approach should be taken as a given.

Additional Missions / Ideas of Potential Importance to Ecological Science and Applications

The group noted the idea of an orbiting transfer radiometer has some appeal. More emphasis on vicarious calibration either in addition to this mission or as an alternative should be pursued. Some expressed concern that cross-calibration is not that easy.

It was noted that several of the new ideas (geostationary for diurnal cycle, coarse resolution SAR, and inexpensive multiple sensors on flights of opportunity) all focused on increasing temporal resolution of land cover and terrestrial ecological science and applications.

A research program using data from as many existing polar orbiters with differing crossing times (i.e., AVHRR, MODIS, SeaWiFS, GLI, etc.) could be undertaken to better define the science requirements for the diurnal cycle (geostationary mission).

The proposed Special Event Imager mission was discussed briefly. Most of the uses discussed centered on meteorological and hydrological observations (surface energy dynamics, weather forecasting, albedo), but canopy conductance and fire were also mentioned. Diurnal sampling is critically needed to improve our ability to remotely sense and monitor fire -- especially in the tropics where morning is clearly the wrong time.

The group had lots of questions about the “inexpensive, multiple sensors on flights of opportunity” mission -- what about platform stability, orbit characteristics, and other such considerations? Pathfinding with existing similar sensors could help here. The group noted that costs saved on launch with these missions might need to be re-allocated, at least in part, for data handling, processing, and analysis -- which would be much more complex in this approach. This becomes an even bigger issue if near real-time processing is desired.

Recommendations Concerning the Missions

The group endorsed the high priority assigned to the two systematic missions (Global Land Cover Inventory for Landsat continuity and Ecosystem Productivity for MODIS continuity) proposed by NASA. Continuity of high spatial resolution and moderate spatial resolution global land imagery is critical for land cover and terrestrial ecology science and applications research. It was felt that the continuity of these systematic observations should be assured through a solid, long-term plan that was economical, yet provided the basic required measurements. NASA should then focus on the planning and implementation of exploratory missions for exciting new observations. The group was supportive of the Ecosystem Response to Disturbance Mission as a first priority for a new exploratory mission, but felt strongly that its scientific rationale should be expanded to include questions of vegetation structure and spatial pattern and that its technological implementation needed further development and evaluation of alternate technologies. Such development was deemed entirely compatible with the notion that this mission would not be flown until after 2004.

NASA and the U.S. Government must find reasonable mechanisms to ensure the continued availability of the Landsat-like and MODIS-like data streams. An operational capability seems best; if so, a long-term plan/policy for Landsat-like observations remains an unresolved national issue and should be a priority for cross-government agency discussion and resolution.

NASA should consider flying the Global Land Cover Inventory (Landsat continuity) and Ecosystem Productivity (MODIS continuity) missions together on the same platform. (Crossing time will need to be resolved.)

NASA should also consider a very high spatial resolution panchromatic band (1-3 m) for the Global Land Cover Inventory mission.

Other new ideas for missions - of which there are several - need further development, both to more clearly identify and articulate their underlying science questions and to weigh and/or develop alternative technological approaches.

NASA must work on advances in data handling and data processing for large volume data sets.

NASA should consider new data Pathfinder activities to make the most of existing data sets and, when possible through data fusion, to explore what data from some of the proposed new missions might look like (e.g., multiple land imagers to explore observational frequency requirements for a geostationary mission or to pathfind data processing issues for multiple sensors on flights of opportunity, or fusion of hyperspatial, radar, and/or lidar for vegetation structure).

The new post-2002 missions must be implemented as part of an integrated system for observations and deriving scientific understanding - these missions cannot be addressed through satellite observations alone.

For those missions that might be pursued through an operational agency program or through the commercial sector, NASA must ensure that a scientific peer review process is in place and accepted by the developer in order for the science community’s requirements and expertise to be infused into the operational/commercial entity’s development and implementation of the mission.

The mission concepts recommended are summarized in Table 2.

TABLE 2

MISSION CONCEPTS RECOMMENDED FOR
LAND COVER/LAND-USE CHANGE AND TERRESTRIAL ECOLOGY

- High Spatial Resolution (~ 30 m) for continuity of Landsat data

- Moderate Spatial Resolution (~ 250 m - 1 km) for continuity of AVHRR/MODIS data until NPOESS flies in 2009

- Commercial Hyperspatial Data Buy (~ 1 m)

- Disturbance / Biomass Response (should be developed as soon as feasible), possibly involving a combination of remote sensing technologies:
  - lidar
  - SAR imaging
  - hyperspatial imaging
  - simple vegetation index
  - wide FOV sensor
  - multi-angle viewing
  - hyperspectral imaging

- Other Exploratory Missions worth further consideration would include:
  - Geostationary
  - Orbiting Transfer Radiometer
  - Coarse Resolution SAR
  - Multi-angle observation

Other Considerations

The group pointed out that there will be increasing uncertainty about what will be important as we project science requirements out to the end of the post-2002 decade. They thought it likely that vegetation structure, composition, and land use will persist as requirements through this time-frame. Hyperspatial, multispectral and lidar technologies offer particular promise to address these needs.

Once future mission concepts are adopted into NASA's plan, it will be very important that the entire NASA program support planning and research activities that will prepare the community to respond when these missions are finally competed. There is great risk that without such preparation there will be a weak competition with insufficient choices and a sub-optimal implementation approach could prevail.

There is a continuing need for a balance between long-term measurements and exploratory measurements and among satellite data, in situ data, process studies, and modeling within the NASA program. The need for a balanced program cannot be over-emphasized.

APPENDIX 5: INTERDISCIPLINARY REPORTS

5.1: HYDROLOGY AND GLOBAL WATER CYCLE GROUP REPORT

In setting priorities for future missions the Group was guided by the following principles:

a. significance of science questions to be addressed.
b. technological feasibility and success probability.
c. value to important applied research and to society at large.
d. potential impact on important policy questions.
e. overall return, in terms of new knowledge and data, from the investment.
f. excitement

Two missions clearly received the highest ranking and were described as urgent and extremely important: The Global Precipitation Mission and the Soil Moisture Observation Mission. The sense of the workshop support the statement that all present would agree that the above two are among the most exciting concepts presented. They are science rich ideas with enormous application and policy implications.

Next in the Hydrology Group priorities are a mission to measure snow and ice and a mission to gage water bodies levels/stage from space, in that order. Although clearly of lesser priority, for a variety of reasons, NASA is encouraged to explore this ideas for the future.

The Global Precipitation Mission

This is a systematic measurements mission building on the successful TRMM experience. The idea is to, for the first time, produce a nearly global (within the 60 degree latitude) precipitation measurement with a sampling interval of 3 hours or less. The concept is to fly a master satellite carrying active and passive instruments and several "drone" satellites with passive sensors. All sensors are proven technologies. The Group considers that this Mission must follow TRMM and it should be scheduled as quickly as possible, not relying on an ATMOS-A concept that seems untenable at the moment. Negotiations with our international partners should begin immediately.

Science Questions

Precipitation over all the oceans and most of the land masses remains unknown. Precipitation, and associated changes in phases of water, is a key factor in the global energy balance and in the global mass balance. Knowledge of precipitation globally is needed to understand climate and its natural and human-induced variability. Precipitation is key to the description and understanding of weather patterns. Precipitation interacts with the oceans and holds a synergistic relationship with phenomena like ocean warming (El Niño). Similarly it is interacts with land masses in phenomena like desertification and in responses to deforestation. Precipitation is one of two main fluxes between the atmosphere and the earth and hence accounts for much of the global hydrologic cycle.

Technological Feasibility

The TRMM Mission and its precursor efforts have proven the concept and the value of measuring precipitation from space. Any technological questions are related to satellite orbits. Technical studies should begin.

Value to Society at Large and Applied Research
As a key weather variable precipitation is crucial to society's daily operations. Global precipitation measurements will have an impact on weather prediction; will serve as calibration and assimilated variables in numerical weather models; will be invaluable to agriculture and water resource management activities; will provide basis for more rational engineering design practices; and will be very important in disaster prevention (particularly floods and landslides).

Policy Implications
The availability of water world-wide is of strategic importance to the nation. For example world food production and its social impact depends on rainfalls. The next century will prove to be one of water crisis, both in terms of quality and quantity. Politically and socially it behooves us to know where and how much precipitation is falling globally.

Overall Returns for the Investment
As previously stated, the type of measurements foreseen simply do not exist, hence this mission provides new knowledge. The technology is proven and hence the risk is fairly small. This type of precipitation data is orders of magnitudes better than what is presently available.

Excitement
Novelty alone is not the origin of all the excitement. Global precipitation measurements are invaluable for atmospheric scientists, oceanographers, ecologists and solid earth/natural disaster scientists. The opportunity for synergism among disciplines is very large. Opportunities also exist for mission synergism, for examples with efforts to measure clouds and aerosols from space.

<u>Soil Moisture Observation Mission</u>
This is a Mission of Opportunity. A Soil Moisture Measuring Mission has been debated over the last 15 years. Finally we have evidence that passive L-band instruments can provide useful information. Furthermore, antenna technology and concepts have progressed to the point that the mission is feasible. NASA should immediately commence technical studies.

Ideally, an L-band soil moisture measurement mission under the current ESSP AO will bring the necessary initial experience with the space deployment of the sensor. More importantly however, it will make possible those science applications that clearly demonstrate the significance of monitoring this variable. The post-2002 follow-up mission will augment the L-band radiometer with an S-band sensor and polarized measurements using an advanced antenna configuration. This will make possible the monitoring of soil moisture at finer scales compatible with the needs of local severe weather and flood hazards activities. The soil moisture measuring mission has enormous potential. It is comparable to TRMM and TOPEX at their origins.

Science Questions
Soil moisture is the key state variable in hydrology: it is the switch that controls the proportion of rainfall that percolates, runs off, or evaporates from the land. Soil moisture is the life-giving substance for vegetation. Soil moisture integrates precipitation and evaporation over periods of days to weeks and introduces a significant element of memory in the atmosphere/land climate system. There is strong climatological and modeling evidence that the fast recycling of water through evapotranspiration and precipitation is the primary factor in the persistence of wet and dry summer anomalies over large continental regions. On this account soil moisture is the most significant boundary condition controlling summer precipitation over the central US and large mid-latitude continental regions, and essential information to initiate seasonal predictions. Soil moisture, together with the ice caps, is the major source of fresh water worldwide and hence a key element in the hydrologic cycle. All of the above are key science questions about which little is known. To answer

them a global view of soil moisture and its variability in space and time is needed. Presently we are limited to rare point measurements, mostly at experimental sites.

Technological Feasibility
The feasibility of using L-band microwave technology to obtain useful soil moisture measurements is proven. It is nevertheless essential to begin studies for the best alternatives for antenna configuration. There are impressive new engineering design alternatives now available for the antenna configuration which must be subject of cost, performance and risk analyses as soon as possible.

Value to Society and Applied Research
Soil moisture is the key variable in agricultural production. Appropriate measurements will allow seasonal predictions of crop yields. A global soil moisture data set will also improve calibration and boundary conditions for weather and climate models. They will be invaluable in flood and landslides predictions. Good soil moisture measurements are also crucial for ecological modeling and predictions. To a large extent, desertification and deforestation effects are integrated in the soil moisture state.

Policy Implications
The strategic importance of world water resources and food production make soil moisture a crucial variable for policy decisions. As stated, soil moisture controls the partition of water between the atmosphere and the different elements of the land-surface water cycle. The knowledge of soil moisture provides the ability for seasonal and longer-term predictions of agricultural productivity and the well being of people throughout the world. If water resources are an issue, knowledge of soil moisture is a necessity.

Overall return for the Investment
Since there are no regional, or global, soil moisture data sets this mission provides completely new information. The impact factor across hydrology, ecology, atmospheric sciences and solid earth sciences would be enormous.

Excitement
Measuring continental soil moisture is the Holy Grail of hydrologists. Finally there is good reason to believe that it will be possible. The atmospheric scientists and the ecologists share the excitement. The novelty of this mission is complete. It also offers the opportunity of synergism with an ocean salinity measurement. The same instrument, an L-band microwave radiometer, can be used for ocean salinity measurements although it is not optimal (an S- band instrument is preferred if salinity is an objective.) The community feels strongly that the soil moisture measurements should not be delayed because of problems related to ocean salinity measurement objectives.

<u>Snow and Ice measuring Mission</u>
From a hydrologic standpoint, snow is a very important input of river basin response. Many river systems flood as a result of snowmelt. Proper prediction of snowmelt is also crucial to forecast streamflow conditions affecting navigation and irrigation practices. Snow and ice also play an important role in the Earth's energy balance, particularly through their significant impact on albedo and the radiation balance. They are integrators of temperature and precipitation and hence contain signatures of climate. Measuring snow and ice extension from space is not new and has been done with a variety of space sensors with various degrees of accuracy. It is important to move to accurate estimation of properties like density, depth, temperature profile, and liquid water content. Measuring snow and ice coverage should become a systematic activity in the future.

Measuring River and Lake Stages from Space

A difficulty facing hydrologists and water resource managers worldwide is the unavailability of timely streamflow discharge data. Existing techniques are fairly primitive point measurements of stage from which discharge is obtained, presuming a stable stage-discharge relationship is available. Many times these observations are not available for political reasons. Nowadays knowledge of streamflow worldwide is of strategic interest since, like soil moisture, it is a surrogate of agricultural potential, among other things. Ultimately NASA and the US should move to estimate river discharges from space. The technology needs further definition. Questions of resolution, accuracy of necessary targeting of the signal, and how to infer the necessary stage-discharge relationship remain.

5.2: ATMOSPHERIC CLIMATE PHYSICS

The Panel finds the proposed missions on Atmospheric Climate Physics extremely important to increasing scientific understanding of the earth system, to assessing the possibility of natural and human induced changes in the environment, and to finding practical ways to cope with environmental change.

The Panel strongly recommends the Aerosol Radiative Forcing Research and the Cloud-Radiation Feedback Research missions in the category of Exploratory and Process Research-Oriented Missions. The Climate Variability and Trend and Total Solar Irradiance Monitoring missions in the Systematic Measurement category are also strongly recommended. These exploratory and systematic measurement missions provide a balanced program and should not be significantly altered. The science questions for each of the missions are reasonably well articulated and address needs that have been expressed by national and international groups.

The Panel recognizes that these missions are not only complex technologically, but also involve many other groups nationally and internationally. In addition, the missions themselves--especially the Cloud-Radiation Feedback and the Aerosol Radiative Forcing Missions--require observations of a number of common parameters. The Panel recommends that the independence of these missions be preserved and the synergism between them be maximized through extensive and intensive early planning.

Similarly, the Systematic Observation missions must be harmonized with the plans of NOAA, DOD, and potential international partners, not only in the context of satellite observations, but also for in-situ observations to accelerate progress towards a truly integrated Global Monitoring Assessment and Prediction System.

The Panel finds that the role of geosynchronous earth orbit satellites in atmospheric climate physics appears to have received only limited consideration up to this time. It is recommended that their role in climate research be reviewed in parallel with the future needs for geostationary satellites required for the provision of weather services to determine the overall direction of the NASA program in this area.

Systematic Measurement Missions

The proposed mission to systematically monitor variability and trends of climate variables and solar irradiance are logical extensions of NASA's program and essential to the long-term monitoring needs to understand and cope with climate variability and change.

The plans for observing total solar irradiance monitoring program appear to be sound and relatively straightforward. Continued cooperation with NOAA, DOD, and international partners with regard to their schedule for launch on NPOESS, including overlap for comparison between instruments, is essential.

The Panel recognizes that the plans for the climate variability and trends mission are far more complex in terms of the variables that should be included, the existing and planned programs of other agencies and nations for satellite and in situ observations, the instruments to be flown on the missions, and, finally, the transition that is envisaged for NPOESS. The panel does recognize the need to provide high quality tropospheric sounding measurements of temperature and humidity between the advanced system on EOS PM-1 and the advanced system being planned for NPOESS. These advanced systems are expected to improve both weather forecasting and climate monitoring capability.

Some of the proposals to add to the list of parameters to be observed with the mission may be satisfied by the plans of other groups. Clearly, the temperature and moisture observations for detection and attribution of global warming must be more accurate than those planned for the NOAA satellites in the next decade. The panel recommends that the planning for these missions be aggressively pursued in cooperation with possible partners. Although costly and possibly technologically challenging, consideration should be given to moving the tropospheric wind profiler into this mission or planning a flight of an incoherent detection Doppler lidar system during the same period. The addition of the wind observations during this period would provide the most comprehensive global observation system ever for development, testing and evaluation of weather and climate models.

Exploratory and Process-research Missions

The Panel agrees that the Aerosol Radiative Forcing and Cloud Radiation Feedback missions are critically needed to understand radiative forcing and feedback processes that have a significant impact on the Earth's climate. New measurements of aerosols and clouds are essential to understanding the causes of observed climate changes and to the development of climate models required to project future climate change for national and international assessments and for policy formulation of actions to cope with climate change.

The role of clouds remains one of the largest uncertainties in projecting future climate changes in response to human-induced changes in atmospheric composition. The cloud feedback mission outlined by NASA will provide global measurements of cloud properties that have not been previously measured, but which are badly needed for understanding cloud feedback and validating climate models.

Aerosols produced by humans are believed to be the largest uncertainty in evaluating the forcing of climate change provided by human activities. Global measurements of aerosols of sufficient quality to determine the precise radiative forcing provided by aerosols are lacking. The aerosol mission proposed by NASA could provide this needed information.

The Panel recommends that the further planning of these missions be done in cooperation with existing national and international research programs, and that a conscious effort be made to entrain scientists from developing countries. Such involvement would be helpful in achieving acceptance of research results in the formulation of policy. The cloud and aerosols missions should retain their separate identities, but at the same time, the planning, including the flight schedule of the satellites, should be done in parallel. Such planning and execution will enhance the scientific value of the missions substantially.

5.3: APPLICATIONS

CONTINUING STRENGTHS

Moderate Resolution Mission (250 m-1 km)

The moderate spatial resolution mission has important science, policy and applications implications for land cover, land use, and terrestrial applications. In addition, this mission has important implications concerning other missions, as it provides the link to human population distributions. Unless some form of long-term measurement is maintained, we stand to lose the potential for gaining an understanding of the long-term dynamics of surface cover change and its relation to physical and anthropogenic forcing functions.

Understanding the dynamics of surface cover change is critical, not only for science, but for issues related to international protocols (e.g. ozone, biodiversity, climate) and topics of concern such as natural hazards and emergency management. Applications with important economic implications will also benefit from this mission: in agriculture, crop yield; in hydrology, modeling of surface conditions; in urban growth management; land cover change. These are only a few examples of where data of this type can improve our understanding.

High Resolution Mission (15 m-30 m)

High spatial resolution imaging is important for land science issues. Such information also has important cross and interdisciplinary implications. This type of data is absolutely central to land science and applications issues. We now have more than a quarter century record in this area. Ongoing science issues in areas such as ecology, terrestrial biology, forestry, and geology have been and continue to be addressed employing this type of data. Policy issues include growth management, environmental resource management, and public health. Applications in precision agriculture, forest management, and urban planning are only a few with important economic consequences.

Commercial High Resolution (Data Buy)

Terrestrial Ecology and Land Use Panel's recommendation for high spatial resolution data is an important component of the science need in the land surface imaging area. We hope that commercial one-meter class instruments will be successfully launched and the science and applications communities look forward to working with NASA to define the high resolution data needed in support of user stakeholders. This will benefit science, applications, and the commercial community.

NEW OPPORTUNITIES

Global Precipitation Mission

Water resources will be a significant constraint on the transition to a more sustainable future in many regions of the world. Currently, many arid and semi-arid regions suffer from periodic drought. Inadequate spatial and temporal information on the distribution of precipitation plagues efforts in both disaster assistance and development planning and management in water stressed areas. The proposed Global Precipitation Mission should be considered as urgent and high priority from an applications perspective. A constellation of satellites mapping precipitation at a sampling interval of three hours or less will significantly advance hydrologic and climate science, provide crucial information for regional and local water management, and will contribute to the peaceful resolution of major policy conflicts related to shared water resources. Planning for this mission should be accelerated.

Advanced Global Imager (AGI)

The Advanced Global Imager (AGI) concept should be pursed as an important bridging mission to continue moderate-resolution multispectral imaging of land and ocean ecosystems in the "gap" between EOS Phase 1 and NPOESS. Multispectral imaging will be the fundamental tool for assessing climate-biosphere interactions. The time series of moderate resolution data from MODIS and AGI could be essential to understanding impacts of climate variability and change on biospheric productivity. These data will also be highly relevant to natural resource management applications and policy.

Special Event Imager (SEI)

The Special Event Imager (SEI) concept could potentially provide unique, high frequency observation of episodic processes in terrestrial and coastal ecosystems that are not easily captured by a dedicated mapping mission. Episodic events (e.g., floods, hurricanes at landfall) often result in dynamic changes that have significant impacts and consequences on ecosystem structure and function and resource productivity. These events can only be fully understood by continuous tracking of critical phenomena. NASA and NOAA should pursue studies of the SEI concept with careful attention to the needs of application user groups.

Public Relevance:

Recent events have created immediate relevance to the nation's Land Cover program and to impacts and consequences of climate variability. Dramatic changes caused by severe weather and population increases will bring this program's research and applications to the public's attention.

CHALLENGES

Long-term Continuity

ESE's foremost challenge is to develop coherent leadership and a vision that is responsive to identified real-world needs and science gaps. Earth System Science is most fundamentally limited by a lack of appropriate observational data to test emerging models. The data most needed to understanding and manage global change are high quality, long-term observations of climate-biosphere interactions.

Data Integration:

The NASA ESE should enhance efforts in the area of data integration and fusion. The current mission scenario is based primarily on a single parameter approach. A successful science and applications mission will require sophisticated integration of multiple data sets in a Geographic Information System analysis and modeling framework.

Broad Participation of the Applications Community:

The NASA ESE planning process is becoming more open and transparent. The next step in opening the process should be more effective use of the Internet to reach a broader community of potential users in the applications area. For example, the RFI response and "blue book" could be posted on the Internet. An announcement of the planning process and request for participation should be posted in widely read publications that reach users in applications areas like agriculture, urban and regional planning, and public health.

5.4: SOLID EARTH SCIENCE AND NATURAL HAZARDS

Introduction

The solid Earth impacts in essential ways all Earth systems, and space offers a unique vantage point for the study of the solid planet. Further, the techniques necessary to address the most important problems in solid Earth science — and of natural hazards in general, including those involving the solid planet — are of critical benefit to other branches of Earth science. For instance, large volcanic eruptions have a significant but still incompletely understood influence on atmospheric chemistry and variations in climate. Earthquakes and volcanic eruptions — beyond their obvious hazards to life and property — can have a strong influence on the shape of the Earth's solid surface, with consequent implications for a variety of phenomena ranging from the generation of tsunamis to soil and slope stability; and, conversely, subtle changes in the Earth topography may provide important warning information on impending seismic and volcanic events. Time-dependent changes in glaciers and ice sheets can be sensitive indicators of climate change. The porosity and permeability of near-surface Earth materials — products of a host of weathering, erosional, depositional, and biological processes— play critical roles in the hydrological cycle and especially in the response of the solid Earth to severe storms and floods.

New Opportunities

Recognizing the need both to limit and to prioritize the most promising new opportunities in any field involving spacecraft missions, we have identified two areas of special promise. In order of priority, they are synthetic aperture radar (SAR) interferometry and high-resolution global gravity.

SAR Interferometry

SAR interferometry has been demonstrated to provide unique, areally continuous information on time-dependent solid-Earth deformation and changes in surface topography associated with fault systems, volcanoes, landslides, and water and ice cover. Such techniques have also been applied to synoptic views of the velocity field of ice sheets and glaciers. The methodology thus has widespread applications to fields as diverse as understanding earthquakes (through measurement of the coseismic and postseismic deformation fields and of possible preseismic strain transients), volcanic hazards (through measurement of pre-eruptive volcano inflation), glaciology, the dynamics of ice flow, and the stability of major ice sheets. The desired measurement requirements are mm-level line-of-sight distance accuracy and 30-100 m positional accuracy, with targetability and repeatability of viewing scenes over the full range of latitudes. Because of the importance of this technology for natural hazard assessment, a capability to carry out SAR interferometry belongs high on NASA's priority list for systematic measurement.

An important product of SAR interferometry, and a critical measurement in its own right, is precise land topography. The topography of the Earth's solid surface, including ice, controls the interaction of the atmosphere and hydrosphere with the solid planet. Knowledge of topography is essential for assessing the global ice budget and for addressing such natural hazards as landslides, floods, and coastal storm surges.

An additional product of SAR interferometry is information on radar backscatter. Changes in backscatter for a given viewing geometry can provide important regionally continuous information on soil moisture and can be used to map changes in flooded regions. Backscatter information can also be related to changes in land cover.

High-resolution Global Gravity

The Earth's gravity field is a fundamental quantity intimately related to the dynamics of both the solid and the fluid Earth, and time-dependent changes in the gravity field provide an extremely promising research tool with which to address problems in hydrology, ocean circulation, sea-level change, glacial unloading, and tectonic deformation. While the Earth System Science Pathfinder mission GRACE will substantially improve knowledge of the Earth's geoid and gravity field for horizontal wavelengths of 300-400 km and greater, and will provide a measure of the time-dependent field over a similar wavelength band, a follow-on mission of improved sensitivity is desirable both to extend the measurement capability to shorter wavelengths and to lengthen the time interval over which temporal field changes can be documented and understood.

Foreseeable improvements can improve the precision in satellite-to-satellite tracking by an order of magnitude over that anticipated for the GRACE mission, extending the resolution of the geoid to wavelengths as short as 100 km, an improvement important both for ocean dynamics and studies of lithospheric deformation. Improved sensitivity at all wavelengths would enhance the ability to measure temporal changes in the gravity field. Such changes can be expected in connection with mass transport associated with the hydrological cycle, changes in ocean bottom pressure and mean sea level, uplift and subsidence of the solid Earth in response to unloading by Pleistocene glaciers and coeval ocean loading, and vertical motions associated with plate tectonics, mountain building, and basin development.

Other Opportunities

There are additional important opportunities for advancing solid Earth science as well as for furthering our understanding of natural hazards through space measurements. These include measuring the time-varying global magnetic field, monitoring the eruption of one or more active volcanoes, and improving the types of geosynchronous observations of severe storms. We have not highlighted these objectives here because of an expectation that these opportunities can be realized through partnerships with other organizations and programs and by taking advantage of platforms flown for other mission objectives.

Continuing Strengths

While the NASA ESE program in Solid Earth Science and Natural Hazards has many strengths that can be expected to continue into the next decade, we restrict mention to two in particular:

- Solid Earth Science has natural scientific and technological links, as noted above, to oceanography, hydrology, atmospheric chemistry, and meteorology. The Solid Earth is an essential aspect of every Earth system.

- The Solid Earth community has a long tradition of international partnerships in the study of the Earth. In geodesy alone, for instance, NASA maintains such partnerships with more than 50 nations.

Challenges

The principal challenges to NASA in the area of Solid Earth Science and Natural Hazards are technical, fiscal, and logistical.

- There is a general need to find methods to lower the costs of missions.

- SAR processing is computationally intensive and presently expensive. The processing efficiency of radar interferometric data needs to be substantially advanced, to the point where real-time interferometry is feasible in the assessment of seismic, volcanic, and other hazards.

- There should be an investment in the technology for improving satellite-to-satellite tracking precision. It appears likely that laser ranging techniques, for instance, can improve on the tracking precision planned for the GRACE mission by an order of magnitude.

- For the Solid Earth Science and Natural Hazards program, an important challenge is to take optimum advantage of geosynchronous platforms for natural hazard assessment and mitigation (e.g., to characterize and track severe storms and to assess air traffic safety).

5.5: OCEANS AND ICE

The Oceans and Ice interdisciplinary panel affirmed the essential elements of the report from the Ocean and Ice Technical Panel. As such, the highest priority for the scientific missions during the 2002-2010 period is maintaining continuity and information content in the several critical oceanographic measurement sequences which will be in existence at the end of the first EOS satellite sequence. It was noted that one of the continuing strengths of the suite of ocean surface measurements lies in the strong international partnership which have been established. Partnerships with France, Germany and Japan, along with US commercial collaboration have established a necessary set of measurements for enabling global climate change studies. A number of international programs,(eg. WOCE,TOGA,WCRP,JGOFS) have provided significant in situ measurements to augment the satellite measurements. The accomplishments of the ESE program to date are significant; a fact which underscores the necessity of ensuring that the program during the next decade protects and enhances the information from the current mission compliment.

The overall program mix of continuing measurements, process measurements, instrument and technology development and science studies was judged to be correct. The ability to consider new mission concepts was viewed as good. The budget constraints with the necessity to maintain continuity in several of the critical ocean time series was viewed as a challenge which may be difficult to meet.

With regard to the issue of measurement continuity, there are two fundamental issues facing NASA in the past 2002 time period. The first issue is defining an acceptable hand off on transition for these critical measurements and the second issue involves defining and implementing the necessary bridging missions to ensure a non-disruptive hand-off.

The time series which were recommended to be continued listed in priority order, are:

1. The continuity of the Ocean Surface Topography Measurements initiated by the TOPEX/POSEIDON and JASON missions was rated as the highest priority for the ocean Ice Panel. These measurements were deemed critical for studying upper ocean circulation and heat transport; monitoring and understanding the cause of long-term sea level change, and addressing energy flux at the air sea interface.

2. The continuity of Vector Wind Measurements of the quality initiated by the Sea-Winds series was rated the second highest priority. These mean surface wind fields deduced from these measurements are essential for understanding and predicting ocean circulation and air-sea exchanges of mass, momentum and energy.

3. Ocean Color Measurements initiated by MODIS. These measurements are critical for studies of the ocean primary production in the oceans and the role of the ocean in the carbon cycle.

4. A time-series of polar ice mass change, averaged over at least 3 to 5 years of inter-annual variability, is required to establish the current rate of ice mass change. This measurement, initiated by ICESat-1 is required to determine the present-day contribution of the polar ice sheets to sea level change.

During the discussion, it was affirmed that there are a number of issues related to maintaining the quality of these measurements which make it difficult to treat them as operational products. The issues identified include the precision of the measurements, the calibration/validation activity required to ensure accurate correction of decadal time series, the specific orbit requirements (both orbit accuracy and ground track repeat path) etc.

The ESE planned mission scenario for the 2002-2010 period was viewed as deficient in two significant areas:

- The break in the ocean surface topography measurements following JASON-1 was viewed with particular concern.
- The adequacy of the transition or hand-off measurements was viewed as questionable for each of the three measurement series.

A JASON follow-on mission to reach the NPOESS time frame was viewed as a fundamental requirement. Further, a critical study of the NPOESS mission is required to establish the adequacy of the NPOESS measurements. Specifically, the NPOESS, as currently planned, does not appear to be an acceptable hand-off mission for continuing the ocean surface topography and vector wind measurements. For the altimeter, the 800 km sun-synchronous orbit raises significant concerns with regard to tidal aliasing and orbit accuracy and the effects of a change in the spatial and temporal sampling must be evaluated, particularly with regard to high frequency geoid error. Further, it was noted that the altimeter for NPOESS is scheduled for only the morning platform which will not be on orbit prior to 2011. This fact would lead to additional concerns about continuity of the time series. The requirement of the Ocean Ice panel for ocean topography measurements could be met by the NPOESS program if a free-flying satellite altimeter were implemented.

The scenario in the ESE plan for continuing the vector wind involved a transition from QuikSCAT to Adios-2 followed by a hand-off to METOP and then to NPOESS. The C-band frequency of METOP raises concerns about the precision of the measurement and the passive polarimetric approach proposed for NPOESS were viewed as having a significant risk in achieving measurements comparable to the Sea-Wind measurements. A single METOP scatterometer is viewed as inadequate for the NOAA/NCEP modeling requirements, which requires that NPOESS provide a vector wind measurement of adequate precision.

With regard to the ocean color, there remains a need for continuity between MODIS and the NPOESS (VIIRS), which is scheduled for launch in 2009, with concern that the 2009 launch date will slip. There is a need for a bridge mission to cover the period following MODIS and prior to the NPOESS launch. The gap filler should have a crossing time within 90 minutes of noon. Further, either a tilting or multiple non-tilting sensors are needed. Finally, there is a need to modify the VIIRS requirements to ensure that specifications on the water-leaving radiance are included and there is no defined polarization or bright target (e.g. clouds) recovery requirement.

New Opportunities

Among the new opportunity missions identified in the ESE missions plan, three were identified as being of particular relevance to the oceans program. The measurement of ocean surface salinity is a key oceanographic parameter which at present is poorly known. Measurement of ocean surface salinity to the accuracy of 0.1 PSU would provide revolutionary information related to the global hydrologic cycle and improving seasonal to interannual climate predictions.

The improved accuracy of the time-dependant gravity field mapping mission would allow enhanced spatial and temporal resolution and would lead to:

- The ability to separate smaller scale gravity signals associated with such signals as ocean bottom currents,
- Improved marine geoid for better determination ocean currents from altimeter data and,
- A better determination of the Mass contribution to the variations in the global sea level record.

Finally, the Special Events Imager was deemed to be important for continuos monitoring of coastal ocean processes.

NPOESS

With regard to the opportunities for continuing the initial EOS measurement with NPOESS, continuity in the transition, consistency in the information content of the EOS and NPOESS series and an established inter satellite calibration/validation effort was deemed essential. Programs such as SIMBIOS which can ensure sensor characterization, on-orbit calibration and sensor intercomparisons must be a part of the transition effort. It was noted by the Oceans Interdisciplinary Panel that a continuing and intensive science oversight of the NPOESS process is needed. This requirement is in sharp contrast to the current lack of insight by the Ocean Ice communities into the NPOESS mission.

Challenges

There were several significant challenges noted by the panel. The first of these was the need for a more vigorous modeling and data assimilation program. Efforts to assimilate topography, winds, sea surface temperatures along with in situ measurements into general ocean circulation models as well as studies with coupled ocean- atmosphere models are required. To implement these data analysis studies, extreme computing resources are required. At present there is inadequate computer resources to support these studies.

A major budget challenge is associated with maintaining the essential decadal time series described earlier in this summary while developing and applying new technology for achieving new measurements.

In this regard, an important further challenge for NASA lies in the identification and prioritization of advanced missions so as to accommodate the needs of the applied science stakeholders. The applied science community interest range from sensor development to the provision of value added services. The challenge of developing a program which satisfies the needs of the application community ,while relying of the opportunities inherent in the national operational satellite program, without compromising the scientific integrity of the existing measurement time series presents a formidable significant challenge.

Finally, there is a need to work with other agencies and the international community to implement supporting in situ programs such as IGOS and GODAE. Finally, it was noted that there are unique requirements for addressing the space/time scales inherent in studying coastal ocean processes and these requirements can best be met from a Geosynchronous Orbiting Satellite.

Findings and Recommendations

Continuation of the Ocean Topography measurements initiated by the TOPEX/Poseidon Mission, the Ocean Surface Wind measurements initiated by the ADEOS Scatterometer and the Ocean Color measurements to be initiated by SeaWiFS and MODIS are to global climate change studies and should be a fundamental part of the post ESE Post 2002 mission profile.

With the evolving scientific questions and evolving technological capabilities for measuring ocean surface topography, winds and ocean color (chlorophyll) , the measurement of these time series cannot be treated, defacto, as operational. In fact, the transition to an operational platform requires, as a minimum, that the information content of the time series available at the end of the initial EOS mission implementations be maintained. This requires extensive calibration, sensor characterization and compatible mission profile characteristics. At present, the currently conceived NPOESS mission does not appear to be an acceptable solution for continuing ocean surface topography and vector wind measurements.

The ESE budget allocation between the continuing measurements, the new process measurements, the technology and demonstration studies and the science investigations was endorsed by the Ocean Interdisciplinary Panel. There was concern expressed about the adequacy of resources to meet the overall program requirements.

Finally, there was a noted deficiency in the number of personnel at headquarters , from the support of the Associate Administrator down, available to manage the overall ESE program. The Ocean and Ice program management, with it’s strong international and multiagency interaction was thought to be particularly undermanned.

Interdisciplinary Issues

The discussion of the Post 2002 flight program raised considerable concerns about the health of the interdisciplinary aspects of the program. Although the overall program objectives as summarized in the program status still contain many of the original objectives of the original program and the proposed ESE Post 2002 mission flight plan recommends continuation of the most important of the original EOS measurement set, the strategy for implementation of studies across disciplinary line was not addressed. Further without a final program plan, which describes the objectives for a complete measurement set, the adequacy of the integrated data set could not be evaluated. This is particularly pertinate in view of the planning guideline that all measurements were subject to replacement(e.g. the clean sheet approach to the Post 2002 mission sequence). Questions raised include how many of the original 28 measurement will be continued and what will be the information content of the continued measurement. In addition to the parameter set composition, the interdisciplinary investigations require continuity for decadal and longer time series Although the issue of continuity for the most important measurements was addressed in the Post 2002 mission profile, there has not been an evaluation of the resulting parameter set by the EOS IWG to ascertain the adequacy of the overall measurements.. Plans for the transition to operational satellites for continuity of the measurements require adequate measurement precision, calibration, and consistent spatial and temporal sampling characteristics.

The critical role of NPOESS in the plans for continuing several critical interdisciplinary measurement sets was addressed. The discussion noted the need for a comprehensive study by the EOS IWG of the NPOESS instrument specification and mission characteristics to ascertain the adequacy to provide measurements of the four measurements targeted for implementation. These are: 1. Earth Surface Parameter, 2. Ozone, 3. Atmospheric Chemistry and Humidity and 4. Total Solar Radiance. There appears to be no acceptable path to continuity of the ALT, ASCAT, and PRECIPITATION measurements using the NPOESS as it is currently structured. The uncertainty in the continuity of these three measurement time series was viewed as an issue of national concern.

Another topic of concern centered on the status of the EOSDIS. Although this topic was not addressed during the meeting, the data products to be provided by the DIS will play a major role in the success of the interdisciplinary investigations. With a reduction in either quantity or diversity of the DIS data products, there will be an impact on the interdisciplinary investigations.

From this discussion, the two recommended actions evolve.

> 1) There should be an ESE oversight team established to assess the measurement set transition to the NPOESS platform.
>
> 2) The current measurement plans should be evaluated by the EOS IWG to establish the adequacy of the measurement set for the interdisciplinary investigation.

5.6: ATMOSPHERIC CHEMISTRY

In addition to discussing specific candidate atmospheric chemistry missions, the Interdisciplinary Panel was asked to comment generally on the RFI process.

The group made the following recommendations:

(1) The ESE should persevere in developing a science-driven program to serve the nation. This is the key to success in implementing "the new way of doing business" and to "prioritizing among disciplines" in selecting missions.

(2a) The ESE should work hard to develop interdisciplinary linkages so that, for example, the aerosol mission developed for climate studies will have a vigorous atmospheric chemistry component addressing the question, "where do these particles come from, what are their chemical and optical properties, and how are these related to their mechanisms of r production and transformation?"

(2b) The ESE should work hard to integrate better the space and in situ observations, modeling, and R&A science.

(3) The new way of doing business should define and implement a focused, limited, high-quality set of measurements. According to the plans we have heard, many of these observations are assumed to transit to NPOESS when it comes on line. We did not see much in the way of contingency planning should this not work, and certainly the range of observations attributed to NPOESS is too vast. *Accordingly, NASA should be prepared for various outcomes of the NPOESS program, including total or partial success, mid-course changes and/or abandonment before completion.*

(4) ESE must devise a successful strategy for data acquisition, processing, fusion, and delivery to the public. This may involve abandoning much of the current investment in the EOS core system.

(5) ESE should initiate "PI/University Class" satellites ($10-20M) in order to stimulate innovation. and attract young people into the field of satellite observations.

APPENDIX 7: ACRONYMS

ACRIM	Active Cavity Radiometer Irradiance Monitor
ADEOS	Advanced Earth Observation Satellite
AGI	Advanced Global Imager
AIRS	Atmospheric Infrared Sounder
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
ASAR	Advanced SAR (Synthetic Aperture Radar)
ASMR	Advanced Scanning Microwave Radiometer
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATMOS	Atmospheric Trace Molecule Spectroscopy
AVHRR	Advanced Very High Resolution Radiometer
BOREAS	Boreal Ecosystem-Atmosphere Study
CEOS	Committee on Earth Observing Satellites
CERES	Clouds and Earth’s Radiant Energy Systems
CFC	Chlorofluorocarbons
CHAMP	German-US gravity mission
CNES	Centre National d’Etudes Spatiales (French Space Agency)
COIS	Navy hyperspectral sensor
CSA	Canadian Space Agency
CZCS	Coastal Zone Color Scanner
DLR	German Aerospace Research Establishment
DIAL	Differential Absorption Lidar
DIARAD	Differential Absolute Radiometer
DMSP	Defense Meteorological Satellite Program
DOI	Department of the Interior
DOD	Department of Defense
ECMWF	European Centre for Medium-range Weather Forecasting
EDC	EROS Data Center (Dept. of Interior)
EGM	Earth Geophysical Model (GSFC project)
ENSO	El Niño-Southern Oscillation
ENVISAT	Environmental Satellite
EO-1	Earth Observation mission (in New Millennium Program)
EOS	Earth Observing System
EOSP	Earth Observing Scanning Polarimeter
ERB	Earth Radiation Budget
ERS	Earth Resource Satellite (ESA))
ESA	European Space Agency
ESE	Earth Science Enterprise
ESPO	Earth Science Program Office
ESSP	Earth System Science Pathfinders
ESTAR	Electrically Scanned Thinned Array Radiometer (ESTAR) Technology
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FEMA	Federal Emergency Management Agency
FOO	Flight of Opportunity
FOV	Field of View
FTIR	Fourier Transform Infrared Radiometer
FTS	Fourier Transform Spectrometer
GAS	Get-Away Special

GCM	General Circulation Models
GCOS	Global Climate Observing System
GFO	Geosat Follow-On mission
GLAS	Geoscience Laser Altimeter System
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GSFC	Goddard Space Flight Center
GTOS	Global Terrestrial Observing System
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HSB	Humidity Sounder for Brazil
ICESat	Ice, Clouds, and Elevation Satellite (Laser altimetry mission)
IEOS	International Earth Observing System
IGOS	Integrated Global Observing Strategy
InSAR	Interferometric SAR
IPO	Integrated Program Office (NPOESS)
IR	Infrared
ISS	International Space Station
Jason-1	NASA/CNES ocean altimetry mission (TOPEX/Poseidon follow-on)
JHU/APL	Johns Hopkins University Applied Physics Lab
JPL	Jet Propulsion Laboratory
LAGEOS	Laser Geodynamics Satellite
Landsat	Land Remote Sensing Satellite
LaRC	Langley Research Center (NASA)
LASE	Lidar Atmospheric Sensing Experiment
LATI	Landsat Advanced Technology Instrument
LC/TE	Land Cover/Terrestrial Ecology
LIDAR	Light Detection and Ranging
LITE	LIDAR-in-space Technology Experiment
LW	Long wavelength
MERIS	Medium-Resolution Imaging Spectrometer
METOP	EUMETSAT Operational Polar Orbiter
MHS	Microwave Humidity Sounder
MISR	Multi-angle Imaging SpectroRadiometer
MLS	Microwave Limb Sounder
MMIC	Monolithic Microwave Integrated Circuit
MMP	Magnetic Mapping Package
MODIS	Moderate-Resolution Imaging Spectroradiometer
MSFC	Marshall Space Flight Center (NASA)
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NDVI	Normalized Difference Vegetation Index
NEMO	Navy Earth Map Observer
NESDIS	National Environment Satellite Data Information Service
NIMA	National Imagery Mapping Agency
NMP	New Millennium Program
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRA	NASA Research Announcement
NRC	National Research Council
NSCAT	NASA Scatterometer

NSF	National Science Foundation
NWP	Numerical Weather Prediction
NWS	National Weather Service
O&I	Oceans and Ice
Oersted	Danish satellite mission
OMB	Office of Management and Budget
PILPS	Project for Intercomparison of Land Surface Parameterization Schemes
POLDER	Polarization and Directionality of Earth's Reflectance
PSC	Polar Stratospheric Cloud
PSU	Practical Salinity Unit
QuikSCAT	NASA scatterometer mission
Radar-Alt	Radar Altimeter
RADARSAT	Synthetic Aperture Radar Satellite (Canada/US)
RFI	Request for Information
SAC-C	Argentine smallsat mission
SAGE	Stratospheric Aerosol and Gas Experiment
SAR	Synthetic Aperture Radar
SeaWiFS	Sea-viewing Wide-Field Sensor
SeaWinds	Successor to NSCAT to be flown on ADEOS-II
SEI	Special Event Imager
SE/NH	Solid Earth and Natural Hazards
SH	Spherical Harmonic
SMM	Solar Maximum Mission
SOHO	Solar Heliospheric Observer
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPARCLE	SPAce Readiness Coherent Lidar Experiment
SRTM	Shuttle Radar Topography Mission
SSC	Stennis Space Center (NASA)
SSM/I	Special Sensor Microwave Imager for DMSP
SSS	Sea Surface Salinity
SUNSAT	South African smallsat program
SW	Short wavelength
TBD	To Be Determined
TES	Thermal IR Emission
TMI	TRMM Microwave Imager
TOA	Top of the Atmosphere
TOMS	Total Ozone Monitoring Spectrometer
TOPEX/POSEIDON	Ocean Topography Experiment (U.S.-France)
TRMM	Tropical Rainfall Measurement Mission
TSI	Total Solar Irradiance
TSIM	Total Solar Irradiance Mission
TSISat	Total Solar Irradiance Satellite
UARS	Upper Atmosphere Research Satellite
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
UV	Ultraviolet
VCL	Vegetation Canopy Lidar
VIIRS	Visible and Infrared Imaging Radiometer Suite
VIRGO	Variability of Solar Irradiance and Gravity Oscillations
VIS/NIR	Visible/Near Infrared